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Estimates of Primary Production and Periphyton Community Structure in the Yellowstone River (Laurel to Huntley, Montana)

by
WATER QUALITY BUREAU

ENVIRONMENTAL SCIENCES DIVISION

Montana Department of Health and Environmental Sciences

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ESTIMATES OF PRIMARY PRODUCTION AND PERIPHYTON COMMUNITY STRUCTURE IN THE YELLOWSTONE RIVER (LAUREL TO HUNTLEY, MONTANA)

Prepared in conjunction with

WASTE LOAD ALLOCATION INVESTIGATION OF THE YELLOWSTONE RIVER
IN THE VICINITY OF BILLINGS, MONTANA

Prepared by

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Water Quality Bureau
Environmental Sciences Division
Montana Department of Health and Environmental Sciences

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To him who in love of nature holds
Communion with her visible forms, she speaks
A various language; . . . . .
Go forth, under the open sky, and list
To Nature's teachings, while from all around --
Earth and her waters, and the depths of air --
Comes a still voice -- . . . . .
By an unfaltering trust, approach thy grave,
Like one who wraps the drapery of his couch
About him, and lies down to pleasant dreams.

--William Cullen Bryant,
From "Thanatopsis"

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ESTIMATES OF PRIMARY PRODUCTION AND PERIPHYTON COMMUNITY STRUCTURE IN THE YELLOWSTONE RIVER (LAUREL TO HUNTLEY, MONTANA)

GENERAL ASPECTS

The reach of the Yellowstone River between Laurel and Huntley has been severely affected by municipal and industrial pollution through past years. Municipal sewage and oil refinery wastes have entered the river in addition to effluents from sugar beet processing and meat packing plants via Yegen Drain. Various storm sewers from the Billings and Laurel municipalities also discharge into this section of the river. Field surveys conducted in the 1950's and 1960's demonstrated a distinct impact of these effluents upon the biota of the river. Evaluations of bottom fauna throughout the Yellowstone Basin were completed in 1955 through a cooperative venture by the Departments of Health of Montana and North Dakota and by the United States Public Health Service ("Yellowstone River Pollution Study," Ref. 1). This study concluded: "Field survey and laboratory results demonstrate heavy pollution and ideal conditions for the development of tastes and odors in the Yellowstone and Bighorn Rivers." In addition, they indicated that pollution" . . . of the river (Yellowstone) is so excessive that an immediate and aggressive program of abatement is fully warranted." A large portion of such an abatement program has been initiated in the Billings area through recent years.

Subsequent surveys in the 1960's demonstrated the continuing effect of wastewater discharges on the river biota. A depression of benthic invertebrates per square foot of river bottom was observed in one study (Ref. 2) -- a reduction to 50 individuals per square foot in sections of the river receiving wastewaters from the 110 individuals common in unaffected waters. In an extreme case, no benthics were collected below the Billings sewage treatment plant, Yegen Drain, and refinery outfalls (Ref. 3). Such depressions were also observed in the 1955 study (Ref. 1). In addition, the percentages of pollution-sensitive organisms--Plecoptera (stoneflies), Ephemeroptera (mayflies), Odonata (dragon and damsel Flies), and Trichoptera (caddis Flies)--were found to decline in a receiving reach relative to the more pollution-tolerant taxa (dipterans-true fly larvae; air-breathing snails-physids; tubificids-blood worms, annelids; midges and blackflies; and the leeches). Pollution-sensitive forms ranged from 74% to 84% above the effluents to lows of 0% to 31% in affected segments (Ref. 2). A study of bottom organisms in 1960 concluded that unfavorable conditions existed in the Yellowstone River between the Billings area and Hysham with generally favorable conditions developing further downstream east of Hysham (Ref. 4). Benthic surveys in 1963 and 1966 suggested that the stream recovered to some extent by the time it reached Huntley (about 15 miles below Billings); benthic invertebrates increased to about 90 per square foot at this site with 87% of these individuals in the pollution-sensitive class (Ref. 3 and 5). However, goldeye fish with an objectional, "oily" taste were caught as far downstream as Pompeys Pillar 25 miles below Huntley (Ref. 3). In general, the Yellowstone River between Billings and Custer was little utilized as a fishery in past years due to such taste-problems in the catch (Ref. 6).

Recent control of pollution sources in the Laurel-Billings reach of the Yellowstone should have resulted in some level of improvement in the river since the completion of these 1950-1960 studies. A recent report by the Montana Water Quality Bureau (1972) summarizes the sources of pollution to the river in Yellowstone County and the recent successes in abatement (Ref. 7). This study concluded that the " . . . near future looks very encouraging. The Yellowstone River is not entirely cleaned-up, but construction of waste disposal facilities during the next two years will provide considerable improvement (Ref. 7)." Corresponding improvement in the river ecosystem through the last 15 to 20 years has been qualitatively suggested by observation (Ref. 8); however, until recently, definite documentation of an improvement in the stream's fauna was not available (Ref. 9). This has been rectified to some extent through the efforts of a waste load allocation study (Ref. 58).

The joint, 1955 study (Ref. 1) also included a survey of bottom flora in the river; this included species lists and relative abundance figures. Such information on attached, benthic plants (periphyton) is of value in that these plants (primarily microscopic diatoms, Bacillariophyceae) are good indicators of water quality and have been often used as a means of evaluating conditions in a river receiving pollution (Ref. 10, 11, 12). The "Yellowstone River Pollution Study" (1955) noted that " . . . algal densities approximating nuisance levels were obtained in the lower Yellowstone in August 1952 (Ref. 1)." They also noted that " . . . algal increases in response to nutrients contained in waste discharges have occurred, and . . . algal stimulation by waste discharges may bring plankton densities to nuisance levels upon frequent occasions." However, extensive analyses of periphyton communities in the Yellowstone River subsequent to 1955 have not been completed until recent years (Ref. 13). A 1965 stream survey did involve periphyton collections, but these were not extensively analyzed due to time limitations (Ref. 6). In addition, very little information concerning primary productivity and algal, standing crop-biomass levels is available for the Yellowstone River at the present time. Some chlorophyll data from periphyton are available from one source for a few scattered sites in the upper river (above Laurel) (Ref. 14).

To fill this void, a periphyton-primary productivity assessment was completed in conjunction with the waste load allocation study. This was included to assess the current "health" of the Yellowstone River in the vicinity of Billings, and its water quality status, and to help document the present, biotic effects of wastewater discharges. Such effects, if present, would be observed as distinct differences between sites in their periphyton communities relative to effluent inputs to the stream. In addition, the occurrence of specific pollution problems can be identified through the presence, absence, or disappearance of particular indicator, diatom species. Primary productivity data provides information on the general eutrophic status of various sections of the river and the stream's potential for producing nuisance algae blooms. In essence, the availability of such data will supply the missing baseline information that is needed for the future management of the stream.

MATERIALS AND METHODS

Sampling Site Locations

Five primary sampling sites were located on the Yellowstone River between Laurel and Huntley, Montana. The upstream site near Laurel (designated as L) was viewed as a control station in being located above the sources of wastewater discharge. Subsequent sites were located downstream at Duck Creek Bridge (D) between Billings and Laurel, at South Bridge (S) and downstream at East Bridge (E), both near Billings, and near Huntley (H). This latter site was located well downstream from the wastewater effluents. Periphyton collections and primary productivity estimates (as chlorophyll accrual rates) were made at all of these locations (Figure 1). (See Ref. 58 for other related sketch maps.)

In addition, several secondary sampling sites were established in the study area for comparison to the primary locations; i.e., secondary sites were located in or near some pollution source. As a result, productivity estimates and periphyton collections were made in the Yellowstone below the confluence of Yegen Drain near the East Bridge (but on the west bank opposite station E) and in the Clarks Fork River near its mouth near Laurel. The latter station was established to assess the effect of high turbidity (characteristic of the Clarks Fork) on primary productivity. A periphyton sample was also obtained from the Yellowstone River below the various discharges from the Corette Plant in Billings (between stations S and E). In addition, an algae sample was collected from the mouth of Yegen Drain _per se_, and floating plant materials (tychoplankton) originating from this drain were obtained from the Yellowstone River.

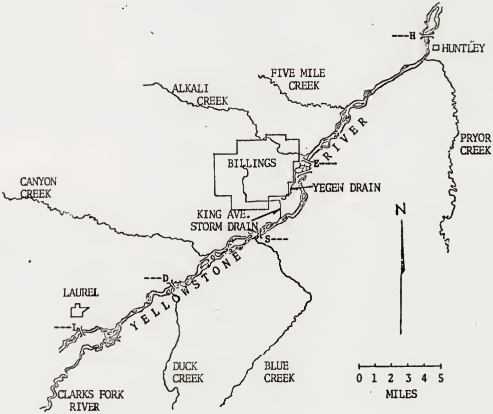
Periphyton Collection and Analyses

Under favorable conditions, diatoms are dominant members of the periphyton community in a stream and are distinct in forming a slippery coating over logs, rocks, and other debris. As a result, a sample of the periphyton community is easily obtained from a stream by simply scraping rocks and other objects with a sharp utensil. In this study, rocks exhibiting a definite diatom development ("brownish film") were obtained from both a riffle area at a sampling site (having a distinct current) and from a backwash section with a very slow current; a number of such rocks were removed and scraped at each location. These procedures allow for the collection of a composite sample that was fairly representative of all the periphyton flora at any particular site. Following the field collections, specimens were immediately preserved in Lugol's (IKI) solution for storage and shipment prior to analyses; samples were sent to Dr. Loren L. Bahls and Peggy A. Bahls (of _Hannaea_ in Helena, Montana) for identification and enumeration.

A complete description of methods employed in specimen preparation and analysis is included in a report prepared by Bahls and Bahls (1975) for the Montana Water Quality Bureau in Billings (Ref. 15). In general, "wet mounts" of the specimens were first prepared for preliminary identification; this was followed by the preparation of permanent mounts (slides) for enumeration. The specimen was severely agitated prior to mounting to insure randomization and "cleaned" with sulfuric acid and potassium dichromate to make the frustules of the diatom more evident.

Cell counts (enumeration) were made under high magnification by viewing successive and unique "fields" through several transects across a slide; counts were made until 300 to 400 individuals had been tabulated. Relative abundance (percent contribution) was then computed for each taxon. From this data, various species diversity analyses were completed such as the Shannon-Weaver

Figure 1. Sketch map of the study area showing the primary sampling sites.



L--Laurel Bridge
D--Duck Creek Bridge
S--South Bridge
E--East Bridge
H--Huntley Bridge

index, redundancy, equitability, diversity, and species richness. As examples, a diatom diversity index (D) was computed using the following equation (Ref. 16):

$$D = \frac{m - 1}{\ln N},$$

where m is the number of species and N the number of diatom cells counted on a slide. An index termed "percentage similarity of community samples" (PS_c) was also computed as (Ref. 17):

$$PS_c = 100 - 0.5 \sum |A-B|,$$

where A and B are the relative abundances of a given species at stations A and B. Such indices are valuable in ascertaining floristic differences between stations, in determining variations in community structure, and in assessing the status of a community relative to wastewater influences.

Estimates of Primary Production

Large aquatic plants cannot become established in the Yellowstone River due to the river's general instability, i.e., due to its annual flooding, scouring, and rechannelization patterns. As a result, the periphyton community, composed primarily of diatoms, represents the dominant plant form in the river and the major source of primary productivity in this lotic ecosystem. An estimate of periphyton growth rates thereby would provide an index to the productivity of the stream. This can be done by estimating rates of chlorophyll accrual on artificial substrates placed into a river; in this case, chlorophyll data were obtained from periphyton that had colonized clean, glass slides suspended in the stream at the various sampling sites.

Microscope slides having a surface area of about 39.5 cm^2 were suspended in the Yellowstone River at each sampling site using modified Catherwood diatometers (Ref. 18). Diatometers were placed so that slides were typically located from 0.8 to 1.5 feet below the surface; in any exposure period, slide depth rarely varied more than six inches between sites. The diatometers were designed so that leading, vertical "wings" or flanges located upstream of the slides would tend to negate current and scouring effects. In general, an attempt was made to place the instruments at a point of medium flow, i.e., not in an extremely slow current where diffusion could pose a problem, nor in a current so swift as to result in slide scouring. Such a placement could not be found at the South Bridge site during the latter phase of the study.

Exposure periods of the slides to the river averaged 8.8 days. After exposure, slides were removed from the river and diatometers and transferred to labelled vials wrapped with aluminum foil to render them light proof. The vials contained 15-20 ml of 90% (V/V) aqueous acetone to leech the chlorophyll from the algal cells attached to the slides. The vial-slide-periphyton preparations were then refrigerated and stored until further analyses could be made. New slides were placed in the diatometers and river sites for the subsequent exposure period.

Chlorophyll concentrations as mg/l (equivalent to ug/ml) were estimated from absorbance data using equations developed by Strickland and Parsons (1972)

(Ref. 19). Absorbancies at 665, 645, 630, and 750 mu were determined for each vial using a Beckman DU Spectrophotometer; the latter wavelength served as a turbidity correction. Absorbancies at 430, 480, and 510 mu were also measured. The ug/ml data for each vial was adjusted to account for the volume of acetone solvent, and pigment concentrations for a site and exposure period were converted to a rate basis for comparative purposes (as ug chlorophyll per day cm^2). Such data for the several exposure periods at each site was then averaged for station to station comparisons.

This phase of the waste load allocation study was run from August 15 to October 15-16, 1975. For the primary sites, this span was split into two segments for confirmatory purposes -- from August 15 to September 9 and from September 9 to October 15-16, with three to five exposure periods in each segment. Site S was discontinued after the first segment. Fewer exposure periods were used for estimating productivity at the secondary sites. Periphyton collections from the various sampling stations were also made during this time span.

Chemical Analyses

Historical data on the chemistry of streams in the study are available from the United States Geological Survey (Ref. 20) and from other sources such as the Montana Water Quality Bureau, Department of Health and Environmental Sciences. Much of this information has been summarized and discussed in a report recently prepared by the Water Quality Bureau (1975) (Ref. 9).

Most chemical parameters have the potential for affecting the aquatic biota to some extent; however, critical nutrient concentrations (ortho- and total phosphate, and ammonia, nitrite-nitrate, and total nitrogen) and total alkalinity-carbon dioxide levels are of major interest since these parameters more directly affect primary productivity. As a result, analyses for these parameters were run periodically throughout the sampling period. Light transmittance and turbidity with their effects on productivity were also regularly monitored at each of the sites. In addition, sampling was completed for certain water quality parameters that were pertinent to the waste load allocation; these are considered elsewhere in the report.

Orthophosphate and total phosphate concentrations were determined with the single reagent method, the latter following a persulfate digestion (Ref. 21). Diazotization and an automated hydrazine reduction was utilized for nitrite-nitrate; ammonia was determined by an automated phenylate method, and total nitrogen was determined through a manual digestion followed by an ammonia analysis (Ref. 21). For total alkalinity, an acid titration was used to a brom-creosol green endpoint (Ref. 22); sample pH was read potentiometrically (Porto-Matic, 175, pH Meter; Instrumentation Laboratory, Inc.), and carbon dioxide was estimated from the pH and alkalinity values using an equation developed by Rainwater and Thatcher (1960) (Ref. 23). However, the high pH values of the samples indicated the occurrence of very low and insignificant carbon dioxide concentrations in the river during the August-October sampling period.

The transmittance of a sample at 550 mu was determined by using a Bausch and Lomb Spectronic 20 (using a one inch tube and light path); corresponding turbidities were read with a Hach Turbidimeter. Percent light penetration to the slides in the river was estimated by converting the transmittance of a sample to absorbance and by multiplying by the corresponding slide depth in inches; total transmittance for a site and date was then obtained by reconverting this calculated absorbance.

RESULTS AND DISCUSSION -- PERIPHYTON ASSESSMENTS

General Features

Algae of the diatom group (Bacillariophyceae) were common in all of the periphyton samples collected from the various sampling sites, and this group represented the dominant element of the flora in samples from the Yellowstone River per se. Between 338 and 370 diatom cells were counted per sample to arrive at the relative abundances of the various species. Through these counts and preliminary sample surveys, 111 different species and varieties of diatoms in 28 genera were recognized through the ten samples. The number of individuals of a species in a sample ranged from those occurring in trace and minute amounts to those comprising greater than 10% of the total. Algae in trace amounts were those species encountered in the preliminary scans of a sample but were then not officially tabulated -- statistically less than one individual per the total counted, less than 0.3%.

Numbers of species encountered in each sample ranged from a low of 39 in the Yellowstone River below the Corette discharges to a high of 63 in the river below Yegen Drain. The relative abundances of the more prevalent diatom species in each of the primary samples-sites is given in Table 1; similar data for the secondary samples-sites is presented in Table 2. Species comprising less than 2% of the counts in any of the samples were combined and compiled in appropriate genera. A complete species list is available in Bahls and Bahls (1975) (Ref. 15).

In addition to the diatoms, several other classes and genera of algae were identified in the samples along with several types of microinvertebrates (Table 3). These were generally encountered in small numbers in the primary sites relative to the Bacillariophyceae. However, a large, filamentous green algae (probably Cladophora glomerata) was quite abundant in the Yellowstone flora at Laurel. Non-diatom species were most commonly abundant at the secondary sites which were more directly affected by pollution. Samples collected from Yegen Drain (periphyton and tychoplankton) were dominated by the bluegreen algae Oscillatoria sp. In the secondary Yellowstone River site below Yegen, Stigeoclonium sp. (a green algae) was abundant with Oscillatoria sp. relatively common. In all of the three samples influenced by Yegen Drain, the interstices of the algal filaments were filled with a fine, filamentous bacterium resembling Sphaerotilus ("sewage fungus"). In addition, at these same sites, nematodes, protozoans, and rotifers were also common. The presence of a large number of heterotrophic bacteria and microinvertebrates is often indicative of an input of outside (allocthonous) organic matter. In addition, the occurrence of a large amount of non-diatom algae as observed at the secondary sites, can be indicative of nutrient enrichment to a stream.

Table 1. Relative abundance (percent) of diatom species in samples collected from primary sites along the Yellowstone River between Laurel and Huntley.

	Sample-Site*				
Prevalent Species	L	D	S	E	H
Achnanthes minutissima	2.0	25.4	25.0	21.0	9.9
Cocconeis placentula	1.7	t	t	t	t
Cymbella affinis	11.6	23.7	21.2	15.8	16.5
Cymbella sinuata	2.0	1.2	1.9	t	0.6
Cymbella ventricosa	1.7	2.3	1.9	1.1	1.2
Diatoma vulgare	15.6	6.7	1.9	5.7	4.9
Epithemia sorex	3.4	0.3	t	0.6	t
Fragilaria vaucheriae	0.6	2.6	1.9	6.0	1.2
Gomphoneis herculeana	3.7	1.8	1.4	1.6	2.3
Gomphonema olivaceum	6.7	2.9	2.2	1.1	2.0
Navicula cryptocephalia	11.1	6.4	9.8	7.7	12.5
Navicula minuscula	0.8	0.6	1.1	0.8	2.0
Navicula mutica	x	x	x	x	x
Navicula viridula	0.8	0.3	0.3	3.1	4.9
Nitzschia acicularis	x	x	0.8	0.8	0.6
Nitzschia dissipata	25.8	7.3	11.1	18.0	19.7
Nitzschia epiphytica	0.6	0.9	1.1	0.3	8.7
Nitzschia frustulum	x	0.3	1.1	2.5	1.2
Nitzschia palea	3.7	4.7	3.0	2.7	4.1
Nitzschia paleacea	x	x	1.9	2.2	x
Nitzschia romana	x	1.2	0.3	0.3	0.9
Surirella ovata	0.6	t	t	0.3	t
Synedra ulna	x	x	x	x	x

Remaining Tabulations	L	D	S	E	H
Achnanthes spp.	0.6	1.5	0.8	0.3	0.9
Amphora sp.	0.3	0.6	1.9	0.6	0.6
Biddulphia sp.	x	x	t	x	x
Caloneis sp.	x	t	t	t	t
Cocconeis sp.	t	t	t	t	t
Cyclotella spp.	t	0.3	1.6	0.8	t
Cymatopleura sp.	t	t	t	t	t
Cymbella spp.	0.3	x	t	t	0.3
Diatoma sp.	x	x	0.3	x	x
Eunotia sp.	x	x	x	0.3	x
Fragilaria sp.	1.1	0.3	x	x	x
Gomphonema spp.	0.6	1.8	2.2	1.7	1.5
Gyrosigma spp.	t	t	x	t	t
Hannaea sp.	0.8	0.3	t	t	t
Melosira spp.	0.6	t	t	0.6	t
Meridion sp.	t	x	x	x	x
Navicula spp.	0.3	2.1	1.6	1.4	1.2
Nitzschia spp.	0.6	2.4	1.7	0.3	1.7
Pinnularia sp.	x	t	x	x	x
Rhoicosphenia sp.	0.6	t	0.5	0.3	0.3
Rhopalodia sp.	0.6	t	x	x	x
Stephanodiscus sp.	x	x	t	t	x
Surirella sp.	t	t	x	t	x
Synedra sp.	x	0.6	x	x	x

*Sequential downstream sites: Yellowstone River near Laurel (L), at Duck Creek Bridge (D), at South Bridge (S), at East Bridge (E), and near Huntley (H); t -- trace amount, x -- absent.

Table 2. Relative abundance (percent) of diatom species in samples collected from secondary sites along the Yellowstone River and tributaries between Laurel and Huntley.

		Sample-Site*			
Prevalent Species	CF	BC	BY	Y	T
Achnanthes minutissima	35.8	18.6	1.7	7.4	8.4
Cocconeis placentula	t	0.3	0.6	1.9	2.2
Cymbella affinis	18.7	42.3	1.7	14.4	7.3
Cymbella sinuata	0.6	0.3	0.3	0.5	0.8
Cymbella ventricosa	3.1	0.3	0.3	1.6	1.4
Diatoma vulgare	0.3	3.0	2.8	3.8	7.3
Epithemia sorex	x	0.9	t	0.3	0.3
Fragilaria vaucheriae	x	0.6	0.6	0.8	1.4
Gomphoneis herculeana	x	0.3	0.3	0.8	1.6
Gomphonema olivaceum	2.6	0.6	x	0.5	2.2
Navicula cryptocephalia	11.8	4.8	30.3	11.2	8.9
Navicula miniscula	3.4	0.9	t	0.3	x
Navicula mutica	x	x	11.7	x	x
Navicula viridula	1.4	0.3	0.3	1.6	0.8
Nitzschia acicularis	t	t	x	1.6	2.7
Nitzschia dissipata	8.7	16.9	5.6	15.5	10.5
Nitzschia epiphytica	1.4	2.1	2.5	0.5	t
Nitzschia frustulum	2.5	x	0.3	0.5	0.5
Nitzschia palea	2.0	1.2	27.8	9.0	11.6
Nitzschia paleacea	x	0.3	t	2.2	2.2
Nitzschia romana	x	x	1.4	4.1	3.2
Surirella ovata	t	x	t	2.4	0.5
Synedra ulna	0.8	0.3	1.2	3.0	2.7

Remaining Tabulations	CF	BC	BY	Y	T
Achnanthes spp.	1.1	0.6	0.9	2.4	2.7
Amphiprora sp.	x	x	x	t	x
Amphora spp.	0.8	0.9	1.1	0.8	1.4
Biddulphia sp.	x	t	t	t	t
Caloneis spp.	x	t	t	t	t
Cocconeis spp.	x	t	0.3	0.8	1.1
Cyclotella spp.	0.3	0.3	0.6	0.3	0.5
Cymatopleura sp.	t	x	t	t	1.4
Cymbella spp.	1.1	t	0.3	0.3	0.3
Denticula sp.	x	x	x	x	t
Diatoma sp.	x	t	t	x	x
Fragilaria sp.	x	x	t	0.8	x
Gomphonema spp.	2.0	2.1	1.5	1.1	1.3
Gyrosigma spp.	t	x	x	0.6	t
Hannaea sp.	x	t	x	0.3	0.3
Melosira spp.	t	x	t	t	0.5
Navicula spp.	0.3	2.4	0.8	5.2	2.8
Nitzschia spp.	1.2	x	4.4	1.2	8.2
Pinnularia sp.	t	x	x	x	x
Rhoicosphenia sp.	0.6	x	1.1	0.5	0.8
Rhopalodia sp.	x	t	t	x	x
Stephanodiscus spp.	x	x	t	x	t
Surirella spp.	t	t	t	0.3	0.3
Synedra spp.	t	x	x	x	t

*Sampling sites: Clarks Fork Yellowstone River (CF), Yellowstone River below Corette Plant (BC), Yellowstone River below Yegen Drain (BY), and Yegen Drain (Y); T -- tychoplankton obtained from the Yellowstone River but originating in Yegen Drain; t -- trace amount, x -- absent.

Table 3. Occurrence of non-diatom algae genera in samples collected from the Yellowstone River and tributaries between Laurel and Huntley; occurrence of microinvertebrates also noted (R -- relatively rare, C -- relatively common, D -- dominant).

Taxon	L	D	S	E	H	CF	BC	BY	Y	T
Chlorophyta (green algae)										
Ankistrodesmus		R		R		R				
Cladophora	C						C			
Cosmarium	R	R	R	R	R	R	C		R	R
Closterium	R	R	R	R	R			R		R
Pediastrium				R						
Planktosphaeria			R	R						
Slenedesmus	R	R		R	R					R
Spirogyra										R
Stigeoclonium			R	R		R		C		R
Ulothrix										R
Cyanophyta (blue-green algae)										
Anabaena			R			R				
Merismopedia				R						
Oscillatoria	R	R	R	R	R			C	D	D
Phormidium					R					
Euglenophyta (Flagellated green)										
Euglena				R		R		R	R	C
"Sphaerotilua-like" filamentous bacteria							C	C		D
Microinvertebrates										
Difflugia (protozoan)				R						
Ptotozoans								R		
Flagellates									R	
Nematodes							C	R		R
Rotifera								C		R

Indicator Species

Species and individuals of the Bacillariophyceae are quite ubiquitous and abundant in aquatic systems; particular species are differently sensitive to various water qualities and have different requirements for their successful ecesis. As a result, diatoms are excellent indicators of the particular quality of water in a stream and of the severity and type of pollution that might be impacting an aquatic system. In addition, since the taxonomy of the group is based upon the shape and ornamentation of their hard and inert, siliceous cell walls (frustules), the various species can be readily identified with the requisite identifying characteristics unaltered upon collection, preservation, transport, and storage. "By careful analysis of a diatom community and a knowledge of community member's ecological 'preferences' and tolerances, a great deal can be ascertained about the habitat and environment (Ref. 24)." Lowe (1974) has recently completed a compilation of the water quality requirements of a variety of freshwater diatoms (Ref. 24).

Ten species of diatoms from the Yellowstone River study area were found to occur in adequate abundances and were found to demonstrate sufficient differences between sites to serve as indicator species. In addition, some information is available on the water quality requirements, preferences, and tolerances of these species. Together these species accounted for 68% to 74% of the individuals counted in samples from the primary sites and 78% to 87% of the individuals counted in samples from the secondary sites on Yellowstone River and the Clarks Fork River. These species accounted for 69% and 59% of the individuals tabulated in the Yegen Drain samples (periphyton and tychoplankton respectively).

Achnanthes minutissima. This species is a cosmopolitan, freshwater form that occurs in both standing and flowing waters. It is periphytic (attached) in nature and has relatively wide ranges of temperature (eurythermal), calcium, iron, and salt tolerances; it is indifferent to pH with best development near pH 7.0 (Ref. 24). A. minutissima is generally characteristic of river zones where the oxidation of biodegradable compounds is complete (oligosaprobic); however, it has been observed to occur in reaches where such oxidation is still extant if adequate levels of oxygen are present (Ref. 24). Generally, concentrations of inorganic nutrients are quite high in waters supporting this species although these waters are not necessarily eutrophic. Since this species is sensitive to low oxygen concentrations, its presence and relative abundance in a reach is a good measure of the biological self-purification of a stream receiving organic wastes (Ref. 25).

This species was present in all of the samples collected during the study (Tables 1 and 2); however, its relative abundance gradually declined through the Billings area from Duck Creek Bridge to Huntley with a pronounced minima in the Yellowstone River below Yegen Drain (and at Laurel).

Cocconeis placentula. This diatom is also a cosmopolitan, freshwater species that occurs in both lotic and lentic habitats; it is generally periphytic, often on larger plants, eurythermal, and is tolerant to a wide range of pH and salt concentrations (Ref. 24). Similar to A. minutissima, C. placentula is oligosaprobic in nature and found with high nutrient concentrations; however, the oxidation of biodegradable material is fairly complete in those aquatic systems that have the diatom (Ref. 24).

The maximum growth of this species is achieved during the fall or spring (Ref. 24). As a result, this species was found only in trace amounts in the Yellowstone River during the period of collection; it was most abundant in those samples related to Yegen Drain and in the Yellowstone River near Laurel (Tables 1 and 2).

Cymbella affinis. C. affinis is a cosmopolitan, freshwater diatom characteristic of flowing or standing waters that have not been exposed to extensive pollution (saprophobic); it achieves its optimum growth during the summer and is best developed in the warmer regions (Ref. 24). Like A. minutissima and C. placentula, this species has a wide range of tolerance to pH and a wide range of "freshwater tolerance" to salt levels; i.e., these three species are indifferently oligohalobous -- freshwater forms occurring in salt concentrations of less than 500 mg/l but tolerant of small amounts of salt (Ref. 24).

In the Yellowstone River study area, C. affinis increased almost fourfold from Laurel to below the Corette discharges, where it achieved its maximum abundance. The relative abundance of this species then declined to the East Bridge sites (with a minimum abundance below Yegen Drain); however, some recovery was evident at the Huntley site (Tables 1 and 2).

Diatoma vulgare. In the Yellowstone River study area, this freshwater diatom had its maximum abundance at Laurel and declined to less than half this level through the Billings area to Huntley. No marked differences in abundance were observed between the river and the Yegen Drain samples.

Bahls (1971) and Lowe (1974) have summarized the ecology of D. vulgare (Ref. 24 and 26). This cosmopolitan species is most commonly found as a member of periphyton communities that inhabit cold to temperate flowing waters (rheophilous). It is dominant in the late summer to early winter in these regions. Although D. vulgare is reported to be eurythermal (able to withstand fluctuations in temperature greater than 15C), it is rarely found in the tropics preferring temperatures that are less than 15C-30C (oligo- to mesothermal). D. vulgare is indifferently oligohalobous and is oligosaprobic in being able to tolerate weaker organic pollution and high nutrient concentrations; this includes nitrogen in the form of ammonia compounds.

Navicula cryptocephala. Lowe (1974) (Ref. 24) describes this species as a ubiquitous and cosmopolitan, periphytic diatom that can be found in a variety of habitats (including lakes, ponds, and bogs, and rivers, springs, and streams), and it can be abundant through a large portion of the year (spring, summer, and fall). In addition, it can be aerophilous in habit (non-submerged). It is a eurythermal species, but like D. vulgare, it prefers water with temperatures less than 30C. Like the previous four species, N. cryptocephala is indifferently oligohalobaus and characteristic of freshwater.

Cholnoky (1968) reported that this diatom occurs under circumstances of intense eutrophication (Ref. 25). Lowe (1974) reports that this species is "tolerant of a broad saprobien spectrum" and is tolerant of a wide range of pH, calcium and oxygen levels (Ref. 24). In the Yellowstone River, this diatom achieved its maximum abundance at the site below Yegen Drain and was less than one-third of this level in all of the other samples.

Navicula mutica. This taxon was found only in one sample -- from the Yellowstone River below Yegen Drain (Tables 1 and 2). Lowe (1974) reports N. mutica to be typically aerophilous and found frequently on the soil (Ref. 24). As a result, the occurrence of this species in the Yellowstone River could be due to an artifact -- sampling at the site of a recent bank collapse or recent overland runoff, or sampling at the time of recent increase in water levels covering previously exposed banks. When located in an aquatic system, N. mutica is characteristic of oxygen-rich springs and streams (Ref. 24).

Nitzschia dissipata. The temperature, pH, and salt tolerances of this cosmopolitan diatom are similar to those of Navicula cryptocephala (Ref. 24). However, this periphytic species is less ubiquitous than N. cryptocephala and is most commonly found in lakes and ponds. In addition, in contrast to N. cryptocephala, this species prospers only in waters with a permanently high dissolved oxygen content (Ref. 25). This species has also been observed in streams. Bahls (1973) found it to be the most abundant diatom in the East Gallatin River and aversive to heavy organic pollution (Ref. 27); it was most abundant in zones where oxidation had been completed with a moderate amount of nutrient enrichment. N. dissipata was common throughout the Yellowstone River in this study with a maximum at Laurel and a minimum below Yegen Drain. It was also abundant in samples collected from the remaining secondary sites.

Nitzschia palea. This periphytic and tychoplanktonic species is similar to Navicula cryptolephala in occurring under circumstances of intense eutrophication. N. palea can be abundant during the spring, summer, and fall and is characteristic of water with high nutrient concentrations (eutrophic); it is often found where the oxidation of organic matter is proceeding and even in the zone of putrefication where oxygen is low or absent (Ref. 24). Lowe (1974) describes this widespread species as "a very good indicator of pollution (and) an obligate nitrogen heterotroph . . . (that) tolerates a wide span of ecological conditions (Ref. 24)." As examples, this freshwater diatom is not only oxygen indifferent, but it is also indifferent to pH, temperature (eurythermal), current, salt levels, and calcium (Ref. 24). Thus the major value of N. palea as an indicator species lies in the fact that it is not rigidly restricted by non-pollution factors (with the exception of biological competition) but is competitively enhanced by the occurrence of pollution-related features. This is illustrated in the Yellowstone River where N. palea is a consistent but relatively insignificant component of the flora except in relation to the samples influenced by Yegen Drain (Tables 1 and 2).

Cholnoky (1960) reported that the proportion of Nitzschia species and individuals in a diatom association is directly indicative of the quantity of dissolved nitrogen compounds. This genera therefore is a suitable indicator of nitrogenous pollution.

Surirella ovata. This species achieves its maximum development during the winter (Ref. 24); as a result, neither the species nor the genera were found to be abundant in the Yellowstone River during the study period (Table 1). It was most abundant in those samples that had been influenced by Yegen Drain (Table 2).

Lowe (1974) describes S. ovata as a rheophilous diatom that is indifferently oligohalobous and eury-oligothermic. This freshwater species is also mesosaprobic to polysaprobic; i.e., S. ovata is commonly found in locations where the oxidation of organic matter is proceeding, or in zones of degradation and putrefication where dissolved oxygen is in low concentrations or totally absent (Ref. 24).

Synedra ulna. Similar to Surirella ovata, this species was totally absent from the primary sites on the Yellowstone River; it was present in small amounts at the secondary sites and achieved its greatest frequency in samples related to Yegen Drain.

Lowe (1974) described this species as being tolerant of high nutrient concentrations (eutrophic conditions) and extreme temperature fluctuations (eurythermal); he also noted that the diatom has a "great ecological span; prefers dirty water; (and is) calcium indifferent (Ref. 24)." In addition, this diatom is commonly found in reaches that have been influenced by organic inputs; however, it is generally found only in segments that have been exposed to a mild pollution or where the oxidation of organic compounds is complete (not in the zone of putrefication).

Minor Species

The above list of ten indicator species found in the Yellowstone River presents a broad spectrum of pollution tolerance and nutrient requirement. This is also the case with the less abundant species of Bacillariophyceae encountered in the sampling program. Several of these remaining species are most characteristic of non-polluted waters, e.g., Achnanthes linearis and Hannaea arcus. In addition, several of the minor species require high levels of oxygen for optimum growth -- Cymbella ventricosa and Rhoicosphenia curvata. In turn, several of the less abundant species are characteristic of polluted waters and eutrophic conditions. These species range from those like Melosira varians which can tolerate extreme pollution (polysaprobic) and low oxygen concentrations to those like Cymatopleura solea and Gomphonema olivaceum which are generally characteristic of less polluted waters (oligosaprobic). Similar to Nitzschia palea, several of the minor species in the Yellowstone River are obligate or facultative, nitrogen heterotrophs (e.g., Cyclotella meneghiniana); these diatoms require a source of organic nitrogen which is often supplied by wastewater, organic effluents.

Diatoms in the Yellowstone River study area, whether relatively abundant or quite rare, are typically known as cosmopolitan and periphytic species; however, some of them have been observed to occur as tychoplanktonic or euplanktonic forms. Several of the species are rheophilic although many are indifferent to current. Thus many of the species are quite ubiquitous and occur in lakes and ponds as well as in streams.

The bulk of the species in the Yellowstone River near Billings are alkaliphilous and occur at pH's around 7.0 with best development over 7.0 (Ref. 24); several of the species however are indifferent to pH and a few tend to be alkalibiontic -- common in alkaline waters. In addition, the major proportion of diatoms in the Yellowstone River study are indifferently oligohalobous. These are freshwater forms that occur in salt concentrations of less than 500 mg/l (specific conductances less than 750 umhos) (Ref. 24); the optimal development of these species however is not markedly affected by salt variations within this range.

Most of the diatoms listed in Tables 1 and 2 are eurythermal which would be expected in waters like the Yellowstone with its wide, seasonal fluctuations in temperature (0C-3.0C in January to 11.0C-24.5C in August, Ref. 29). Most of the species are oligo-mesothermal requiring temperatures of less than 30C for optimal growth. The seasonal optimums of the 111 species of diatoms are variable with at least some species potentially abundant in the river during each season of the year.

Community Aspects

Subtle, longitudinal changes are generally evident in the floristic structure and composition of rheophilic periphyton. As indicated in Table 1, this was observed in the Yellowstone River between Laurel and Huntley where the floral composition of periphyton in the river at Duck Creek Bridge was different from that at Huntley. This is further illustrated in Figure 2 which shows the relative abundances of the four most common species of diatoms (comprising 50% to 67% of the total) at the five primary sites of the study area. Such floristic differences between sites are due in part to (1) small and accumulative, gradual alterations in physical and chemical parameters that occur naturally downstream, and to (2) the varying tolerances and requirements of the diatom species to these differences. In addition, the natural floristic changes in a stream can be accentuated and altered by man-related disturbances, e.g., by wastewater inputs of various types. The changes in the Yellowstone River flora probably result from a combination of these factors. The relative abundances of these more common species are additionally variable if the secondary sites are also considered (Table 2).

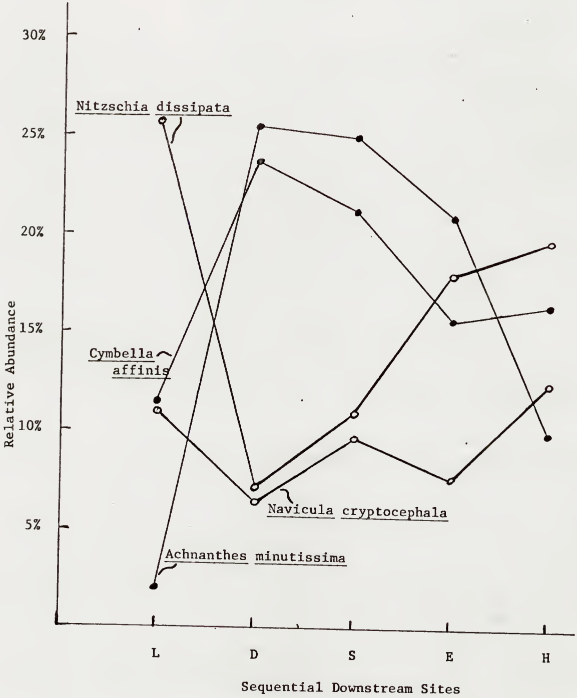
The extent of floristic similarity between sites can be illustrated by using the index of percentage similarity (PS_c) between corresponding samples. As defined previously, this index can vary from 100 to zero. The former indicates a perfect correspondence in periphyton species and relative abundance between samples; values approaching zero indicate the opposite case, i.e., a high degree of dissimilarity.

Since there are gradual changes in the diatom composition of streams, a perfect correspondence of species would not be consistently expected in samples from two distinct sites. However, if the sites happened to be relatively close together, quite high PS_c values would be obtained in most natural situations. As the sites become progressively farther apart, lower PS_c values would be expected in response to the greater physical and chemical differences that could develop between the more widely-spaced locations. In the natural case, PS_c might be interpreted as varying as a function of the distance between two sampling points. A relatively low PS_c value from samples of two closely-spaced sites, however, would be distinctive and meaningful and could be indicative of some intermediate input that causes a marked physical and chemical change in the stream.

A matrix of percentage similarity values between samples from the five primary sites is given in Table 4. Pertinent comparisons involving samples from the secondary sites are also presented in the table.

With the exception of the Laurel location on the Yellowstone River, the percentage similarity of periphyton is greatest between samples from adjacent primary sites and is quite high in these cases, falling between 73% and 80%.

Figure 2. Relative abundance of four species of diatoms collected from five sites on the Yellowstone River between Laurel (L) and Huntley (H); D--at Duck Creek Bridge between Billings and Laurel, S and E-- at South Bridge and at East Bridge near Billings.



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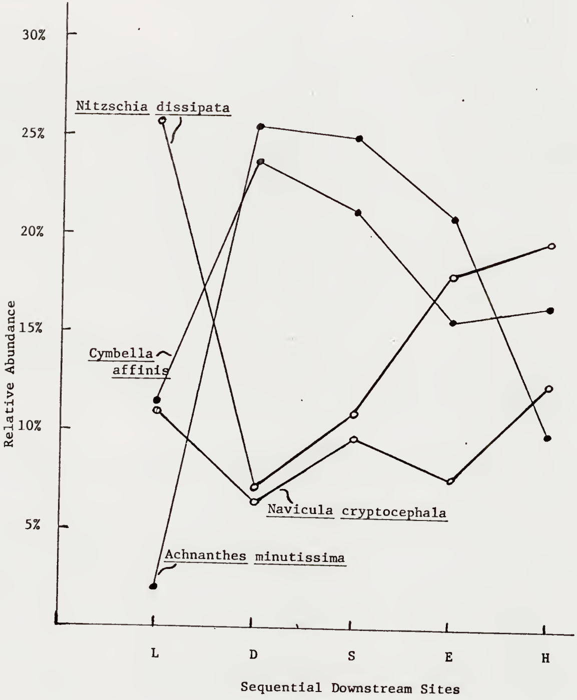


Table 4. Matrix of percentage similarity of periphyton samples from five primary sites on the Yellowstone River and pertinent comparisons from various secondary locations. Sequential primary sites downstream: Yellowstone River at or near Laurel (L), Duck Creek Bridge (D), South Bridge (S), East Bridge (E), and Huntley (H). Secondary sites: Clarks Fork River mouth (CF) (between sites L and D), Yellowstone River below Corette (BC) (between sites S and E) and below Yegen Drain (BY) (across from site E).

	Primary Sites				
	L	D	S	E	H
L	X	51.2	52.0	57.6	64.7
D	51.2	X	79.7	70.4	63.0
S	52.0	79.7	X	76.3	67.1
E	57.6	70.4	76.3	X	73.1
H	64.7	63.0	67.1	73.1	X
Secondary Sites					
CF	42.4	71.2	75.5	63.3	59.3
BC			67.4	67.3	
BY				25.6	

Similarity then sequentially declines in the subsequent upstream and downstream locations; such changes in similarity, however, are relatively small. The greatest percent change in floral composition occurs between sites D and H (17%), and these sites are relatively far apart. This suggests that there are no marked alterations in the periphyton flora of the river downstream from site D to Huntley.

This is apparently not the case upstream from site D. Percentage similarity (PS_c) values in Table 4 indicate that there is a distinct dissimilarity in floral composition between the sample from site L and the other primary samples. In this case, floral similarity becomes progressively greater downstream to Huntley. This is suggestive of a major input to the Yellowstone River between sites D and L during the period of collection which affected the periphyton of the stream (possibly the Clarks Fork River which joins the Yellowstone between these two locations).

Disparities are also evident in the floral composition of some of the secondary, periphytic comparisons (Table 4). The Clarks Fork periphyton was found to be quite similar to that in the Yellowstone River below its confluence with a general decline in similarity farther downstream to Huntley. However, the Clarks Fork periphyton flora was distinctively different from that in the Yellowstone River upstream from their confluence (at the Laurel site on the Yellowstone). This is also suggestive of an effect of the Clarks Fork on the Yellowstone.

Percentage similarity of flora decreases slightly in the Yellowstone River below the Corette Plant discharges between sites S and E (Table 4); this is indicative of a mild influence by these inputs. However, the high similarity between the S and E samples (76%) indicates a general recovery of the stream. More distinctive is the effect of Yegen Drain on a segment of the river at Billings. This is illustrated by the low similarity of flora in the E samples to that collected across the river below the confluence of the drain. However, the high floral similarity of the E sample to the sample collected downstream at Huntley indicates that the river is not severely nor permanently affected by this wastewater input. A high percentage similarity in diatom composition was obtained between the Yegen Drain sample and the tychoplankton (floating) sample collected from the Yellowstone River (72%); this would be expected since the latter sample was derived from periphyton located in the drain.

Suitable indicator species have broad or narrow tolerance to critical components in wastewater effluents; as a result, the presence or absence of particular species in a stream serve as valuable diagnostic tools for detecting pollution. However, the detectable occurrence or non-occurrence of a particular diatom in a stream may also be a function of natural factors and seasonal influences. In addition, the relative abundance of an indicator species is not necessarily indicative of the quantitative degree of pollution that might be impinging upon a stream. As a result, aquatic ecologists have also directed their attention to the total algal association or periphyton community in a stream as a means of assessing water quality.

Healthy streams have a large number of species with most in relatively small populations (Ref. 30); several of the species might be categorized as being relatively common with the bulk of the diatoms classified as being rare.

In addition, healthy or natural periphyton communities are dominated by the diatom group. The effect of pollution is to decrease the number of species and to greatly increase the abundance of a few tolerant species which then become extremely common. In addition, the community becomes enriched with non-diatom algae such as the filamentous greens, bluegreens, and euglenoids. These relationships can be expressed mathematically through the use of various diversity indices. The diversity index devised by Margalef (1951) (Ref. 16) has been described previously. Since this index is based on the number of species per total number of individuals counted, a healthy stream will be characterized by the high diversity index of its periphyton.

In addition to the index of diversity, four other valuable parameters or indices can be derived through considerations of the total algal community. These also serve as diagnostic tools and can be described as follows:

1. Shannon-Weaver function. This is another type of diversity index. A Shannon-Weaver index that is greater than 3.0 generally indicates a healthy community while values that are less than 1.0 indicate communities under stress (Ref. 31). A review of literature describing unpolluted waters revealed that this index ranged from 3.0 to 4.0 in healthy macroinvertebrate communities (Ref. 32).

2. Redundancy. This index expresses the dominance of a few species; it is minimal when there are a large number of species (unpolluted waters) and maximal when a few species dominate a community (polluted waters) (Ref. 33). Calculations indicate that healthy streams have redundancies of less than 0.5; values greater than 0.5 are suggestive of some type of stress, and values exceeding 0.6 are indicative of relatively low diversities in a stream.

3. Species richness. This index is essentially the antithesis of redundancy; it has its maximal values when there are a large number of species in a community. This index becomes similar to the Shannon-Weaver function as large numbers of individuals are counted in a community sample. As a result, values between 3.0 and 4.0 are indicative of a healthy community; lower values are suggestive of the depressed species richness that develops in polluted waters. However, low values can also be obtained if an inadequate number of individuals are tabulated for a sample.

4. Equitability. This index was devised to compare an actual, empirical species distribution to a theoretical distribution that is assumed to occur in unpolluted waters; this index was found to be more sensitive to cases of mild degradation than the diversity indices (Ref. 32). A perfect comparison between the theoretical and empirical distributions results in an equitability of one; this index then rapidly declines in polluted waters. Values of equitability that are greater than 0.5 generally indicate a lack of degradation; values slightly less than 0.5 indicate a mild degradation while values between 0.0 and 0.3 are suggestive of more severe forms of pollution (Ref. 32).

These four "community" variables are mathematically defined and summarized in Newell (1975) (Ref. 33). These indices have been computed for the periphyton samples collected from the Yellowstone River study area. These values (Table 5) can then be compared to the critical limits described above for each index to provide another means for assessing conditions in the Yellowstone River.

Discussion

The 30 to 35 mile reach of the Yellowstone River in the study area presents a gradual, downstream successional continuum in the composition of its periphyton. This is illustrated in Figure 2 and in the PS_c values of Table 4. However, such changes in periphyton are typical of stream ecosystems and are therefore not necessarily related to man's influence. The abundance of *Achnanthes minutissima*, *Cymbella affinis*, *Diatoma vulgare*, and *Nitzschia dissipata* in samples from all of the primary sites (Table 1) indicates that the river is well oxygenated and not affected by severe organic pollution. These four species, particularly *C. affinis* which is saprophobic, are aversive to pronounced organic pollution and require high levels of oxygen for optimum development. High oxygen levels are also required by *Cymbella ventricosa* and *Fragilaria vaucheriae* which were found at all of the primary sites but in small amounts. In turn, the absence or rarity of *Surirella ovata* and *Synedra ulna* in primary samples from the stream are also suggestive of a lack of extensive organic pollution; these species are most characteristic of streams that have been impacted by organic effluents. *Nitzschia palea* is also relatively rare in the Yellowstone River in contrast to its abundance in samples affected by Yegen Drain (Table 2). Since *N. palea* is characteristic of polluted streams, this would again be commensurate with a general lack of organic pollution in the Yellowstone in contrast to Yegen Drain which is affected in this manner. In addition, the small contribution of the non-diatomaceous algae to the periphyton flora of the mainstream Yellowstone (Table 3) is also indicative of a healthy stream.

These considerations of various indicator species suggest that the effects of wastewater effluents on the Yellowstone River in the study area are relatively mild at the present time. Some effects can be seen, however, as illustrated in Figure 2. Two distinct patterns of abundance through the primary sites are evident in these four species. Two diatoms (*Acnanthes minutissima* and *Cymbella affinis*) might be best described as "decreasers" with a general decline in abundance from site D to Huntley. In turn, the other two species are then "increasers" (*Navicula cryptocephala* and particularly *Nitzschia dissipata*) with an increase in abundance downstream. The "decreasers" can be classified as quite sensitive to pollution while the increasers are more tolerant of pollution (particularly *N. cryptocephala*). Such a gradual shift in the abundance and dominance of these particular species could be related to the various wastewater effluents that sequentially enter the Yellowstone River through the study area. These inputs would cause a decline in the more sensitive diatoms allowing for an increase in the tolerant forms. However, *N. dissipata* is aversive to severe organic pollution; thus, the effects of the wastewater inputs can be judged as relatively mild. Such relationships between the "increasers" and "decreasers" in the main river below site D, however, would have to suggest that the river at the upstream "control" station (site L) is similarly affected (see Figure 2).

Table 5. Diversity, redundancy, species richness, and equitability of periphyton samples collected from the Yellowstone River and pertinent tributaries.

	Yellowstone River at or near:									
	Primary Sites					Secondary Sites				
Index	Laurel	Duck Creek Bridge	South Bridge	East Bridge	Huntley	Below Corette	Below Yegen	Clarks Fork	Yegen	Tychoplankton
Diversity (Margalef)	5.29	5.48	6.09	5.93	5.13	4.47	6.12	4.59	8.13	8.62
Diversity (Shannon)	3.74	3.66	3.81	3.83	3.87	2.80	3.31	3.27	4.47	4.83
Redundancy	0.30	0.33	0.33	0.32	0.26	0.49	0.45	0.38	0.27	0.20
Species Richness	3.30	3.23	3.36	3.38	3.41	2.47	2.92	2.89	3.94	4.27
Equitability	0.44	0.44	0.45	0.45	0.46	0.33	0.39	0.39	0.52	0.56

Evidence from the periphyton data indicates that there is a general nutrient enrichment in the Yellowstone River through the study area. The proportion of Nitzschia species generally increases through the downstream samples as does the number of individuals in this genera (Figure 3). As noted, a high percentage of Nitzschia species and cells in a sample is a good indication of nitrogen enrichment. In addition, a large number of the abundant species found throughout the Yellowstone River are also common in eutrophic waters, including Diatoma vulgare, Gomphonema olivaceum, Navicula viridula, and Nitzschia dissipata among others, and some are obligate nitrogen heterotrophs (e.g., Nitzschia frustulum and Nitzschia palea). However, the occurrence of these species in the river does not necessarily mean that the stream is in a eutrophic condition; estimations of primary productivity are needed for making such judgments. These were included as a part of the study.

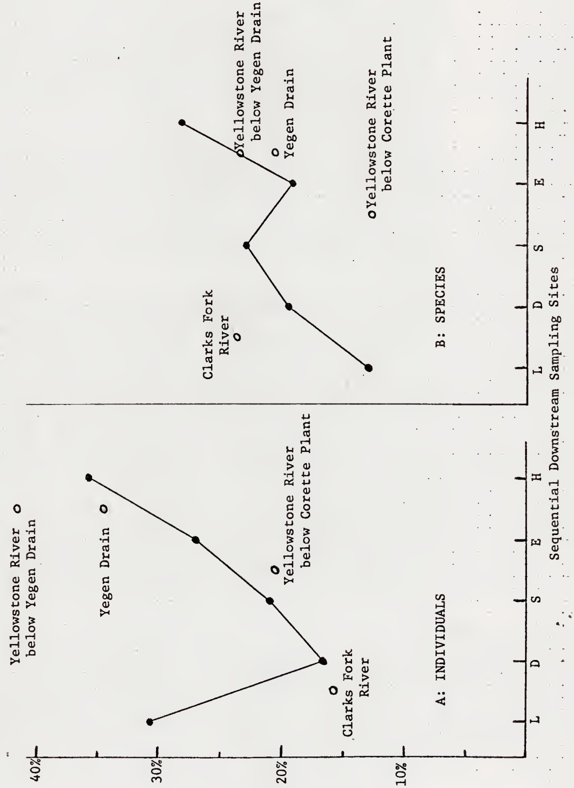
Certain influences can be detected in the downstream periphyton continuum of the Yellowstone River. Three of these influences stand out in particular--the Corette discharges (warm condenser water and ash pond discharges), Yegen Drain, and the Clarks Fork River. Each of these affects the river flora in a different way, and all of these cases caused PS_c decreases (Table 4).

The diatom association below the Corette discharge was dominated by Cymbella affinis, a summer season diatom apparently prospering in this location because of an elevated temperature resulting from the discharge. This abundance of C. affinis helped depress diatom diversity to the lowest level recorded in the present study (Table 5). Conversely, the abundance of a saprophobic diatom like C. affinis and the relatively minor importance of Nitzschia (Table 2) indicate chemical water quality below the Corette discharge to be rather good. The stress causing depressed diversity at this location appears to be brought on by temperature rather than by some chemical constituent. The high PS_c value between sites S and E indicates that the river rapidly recovers downstream.

The influence of Yegen Drain on the Yellowstone River periphyton is one of gross nutrient enrichment. This is substantiated by a number of observations: (1) the abundance of Oscillatoria sp., Stigeoclonium sp. and a Sphaerotilus-like bacterium in and below the drain (Table 3); (2) minima for both Achnanthes minutissima and Cymbella affinis below the drain; (3) maxima for both Navicula cryptocephala and Nitzschia palea below the drain; and (4) a peak in the percent contribution of Nitzschia cells below the drain (Table 2). The effect of Yegen Drain on the Yellowstone River is also evident in the dissimilarity of flora between samples taken from site E and from across the river (Table 4) (low PS_c). However, a rapid recovery is suggested by the high PS_c value between sites E and H.

A case might also be made for nutrient enrichment at the Laurel site: the relative lows of Achnanthes minutissima and Cymbella affinis (Figure 2) coupled with the uniquely high abundances of Epithemia sorex, Comphonema olivaceum, and Diatoma vulgare (Table 1), plus the high proportion of Nitzschia sp. cells (Figure 3), are all characteristic of eutrophic waters. These aspects were unexpected since site L was viewed as a "control" site above the major wastewater inputs of the Billings area. Other data from the Laurel section of the river also supports this contention (Ref. 34); low abundances of A. minutissima and C. affinis were again obtained (5% and 11%) with a high proportion of Nitzschia sp. (37%) and E. sorex (12%). Since similar relation-

Figure 3. A: The percent contribution of all Nitzschia sp. cells to the total cell count of each sample; B: the number of Nitzschia species as a percent of the total number of species in each sample. L-H are sequential downstream sampling sites on the Yellowstone River: L--Laurel, D--Duck Creek Bridge, S--South Bridge, E--East Bridge, and H--Huntley.



ships were obtained about 30 miles upstream near Columbus -- A. minutissima (1%), C. affinis (1%), E. sorex (20%), D. vulgare (24%), and Nitzschia sp. (28%); the occurrence of high, background nutrient levels is suggested for the river above Laurel (Ref. 34). However, because the predominant Nitzschia sp. is the oxygen-dependent N. dissipata and because diversity is generally quite good (Table 5), the periphyton in the stream at Laurel is apparently under no great stress from either organic pollution or low dissolved oxygen.

Despite the somewhat low diversity indices at the mouth of the Clarks Fork River (Table 5), water quality appears to be relatively good given the type of prevalent periphyton species found at this location. The relative abundances of pollution sensitive diatoms are high (C. affinis and A. minutissma), and those diatoms characteristic of eutrophication and organic loading are relatively rare (Table 2). There is a relatively high proportion of Nitzschia species in the sample from this location which may be indicative of a high nitrogen level in the river.

In general, the Clarks Fork has no major discernible, negative effect on the Yellowstone River at site D other than possibly some nitrogen enrichment since Nitzschia sp. increase in the mainstream below the confluence of the two streams. The distinct floristic difference between sites L and D above and below the Clarks Fork, has been previously noted; however, such changes in diatom composition might be interpreted as denoting a beneficial alteration in water quality as well as a detrimental one given the major increases in pollution sensitive forms to site D.

Various community features of the Yellowstone River periphyton also indicate that the stream is in a healthy condition at the present time. Patrick (1954) (Ref. 18) demonstrated that a diatom sample from a natural freshwater stream typically provided a truncated, normal curve when numbers of species (Y-axis) were graphed against a corresponding range of individuals (X-axis) (Figure 4). The height of the curve was generally greater than eighteen species with a large number of species having less than 64 individuals per 5000-8000 cells counted; only a very few species had counts ranging between 500 and 1000 cells. Organic pollution was found to reduce and flatten the height of the curve to about twelve species with a smaller number of species having less than 64 individuals; several species, however, had counts exceeding 1000 individuals in this case (Figure 4). Severe organic pollution resulted in a further flattening, reduction, and extension of the curve. In addition, other types of curve patterns were observed in response to different forms of pollution. For example, a toxic pollution that affected all species was also found to decrease the height of the curve but without an extension to species having large numbers of individuals. Results of this nature, as obtained by Patrick (Ref. 30 and 18), are summarized in a tabular form (Table 6) for comparison to the periphyton data from the Yellowstone River.

Table 6 indicates that the community structure of the periphyton from the Yellowstone River most closely resembles the truncated-normal data from an unpolluted freshwater stream. As indicated in the table, major differences were obtained in some or all of the variables through the other comparisons. This indicates that an extensive organic or toxic pollution which could markedly affect the periphyton flora is not entering the river in the study area at the present time. The closest similarity between the Yellowstone and a form of pollution is that of a seasonal effect.

Figure 4. Relationship between species and individuals in an unpolluted stream (Ridley Creek, Pennsylvania) and in a stream affected by organic pollution (Back River, Maryland)(taken from Patrick, 1973).

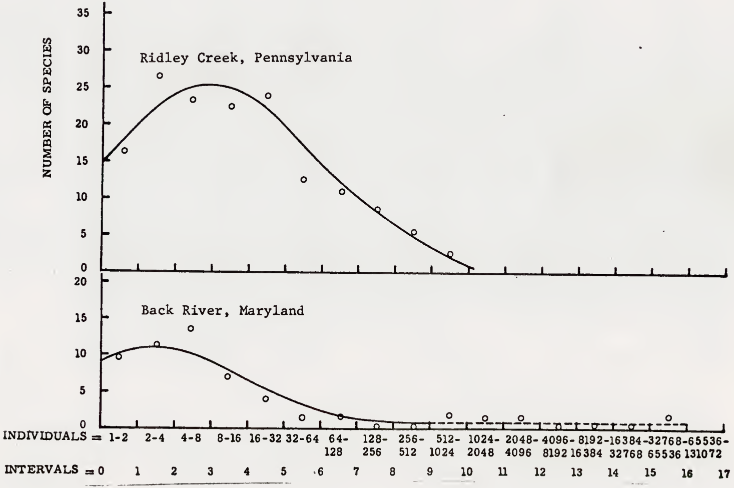


Table 6. Number of diatom, periphyton species with a particular range of individual tabulations observed under various conditions of stream pollution (modified from Patrick, 1973); other pertinent variables and corresponding Yellowstone River data also included for comparison.

	Types of Pollution - Numbers of Species*						
Individuals	Natural Case (Unpolluted)	Mild Organic Pollution	Severe Organic Pollution	General Toxic Pollution (a)	Specific Toxic Pollution (b)	Seasonal Pollution (c)	Yellowstone River
<8	63	31*	24*	33*	30*	54	59
8-64	61	17*	14*	17*	15*	44	34
64-2048	27	8*	13*	11*	10*	16	18
2048-16,384	0	4*	3*	0	3*	0	0
>16,384	0	0	1*	0	0	0	0
Total Species	151	60*	55*	61*	58*	114	111
Total Individuals	8,000	29,000*	87,000*	5,000*	34,000*	4,500*	8,000
% (d)	24%	42%	56%	31%	72%	26%	38%
Individuals/species	53	480*	1,600*	82	590*	39*	72
River Diversity	16.7	5.7*	4.74*	7.0*	5.5*	13.4	12.2

* An asterisk denotes a relatively major and critical deviation from the natural case.

(a) All species affected by the toxicant.

(b) A few species tolerant of the toxicant.

(c) Species affected by seasonal influences during the reproductive phase, e.g., low pH in the spring.

(d) Percentage of individuals due to the most common species.

Samples that provide a curve similar to that of Ridley Creek in Figure 4 also have high diversity indices. The quantitative significance of the Shannon-Weaver diversity index and of the other indices based on community structure have been described previously. All of the periphyton samples collected from the Yellowstone study area, with one exception, had Shannon-Weaver diversities greater than 3.0 (Table 5) which is indicative of a healthy stream. The Margalef diversity index was also relatively high in most of the samples. The Shannon-Weaver index is suggestive of a slight increase in diversity downstream; however, both indices were fairly even through the study area except for a slight depression below the Corette Plant.

Diversity was surprisingly high in the Yellowstone River below Yegen Drain and even in the drain itself regardless of its purported organic load. Apparently, organic pollution carried by the drain does not markedly restrict the number of species inhabiting the Yellowstone below its confluence. This would indicate that most of the organic matter carried by Yegen Drain had been oxidized prior to reaching its mouth. The main effect then of the drain appears to be a nutrient enrichment of the river as illustrated by the increase of Nitzschia sp. from site E to H (Figure 3). However, such nitrogen heterotrophs, as common in the Nitzschiae, are important components of the self-purification system in streams due to their ability to utilize organic, nitrogenous compounds commonly present in wastewaters.

In addition to diversity, the range of redundancy in the Yellowstone samples (less than 0.5) also indicates an absence of major pollution in the stream; similar conclusions can be drawn from the species richness of the samples (Table 5). Of the various indices in Table 5, only the more diagnostically sensitive equitability values from the Yellowstone samples (less than 0.5) are suggestive of a mild pollution problem. Equitability is lowest in the Yellowstone below Corette and Yegen Drain indicating the occurrence of some water quality alternations via these discharges. In general, all of these indices suggest that the Yellowstone River is not being impacted by major forms of pollution; such effects are mild at worse (equitability less than 0.5 but greater than 0.3), and only moderate and longitudinally temporary levels of degradation are evident in relation to specific point-source inputs of wastewater. These indices also indicate that the Clarks Fork River has a small to negligible effect on the Yellowstone.

About one-half of the 301 species of diatoms described by Lowe (1974) (Ref. 24) can be generally classified in relation to their pollution tolerances. Of these species, 48% could not be categorized in this manner due to a lack of ecological information. Of the remaining 158 species and varieties, 23% are characteristic of unpolluted water (sensitive), 70% of weak pollution (semi-tolerant), and only 8% are tolerant of extreme levels of organic pollution. Not all of these species are found in the Yellowstone River nor in any single aquatic system. With random selections of 111 of these diatoms, a species distribution approaching the above proportions would be obtained. In an actual case where pollution is a factor however, a shift in the distribution would be expected to a higher proportion of more tolerant forms. With a greater stress, a more pronounced shift would be expected to an extreme case of 100% tolerant under severe conditions, e.g., putrefication.

The 111 species and varieties of diatoms in the Yellowstone River were similarly classified for comparitive purposes; 56% of these could not be categorized. The remaining 49 types of diatoms provided the following distribution: sensitive--14%, semi-tolerant--73%, and tolerant--12%. This distribution is generally similar to one obtained by random selection although a slightly higher proportion of both semi-tolerant and tolerant forms was obtained from the Yellowstone. This would indicate that the river is possibly affected by a mild pollution problem at the present time, as illustrated by the equitability values, but the river does not appear to be affected by any marked pollutive stress.

RESULTS AND DISCUSSION--PRIMARY PRODUCTIVITY

General Features

Biological surveys of the Yellowstone River in the vicinity of Billings prior to the pollution abatement efforts of recent years revealed that the river was in or approaching a eutrophic condition at that time (Ref. 1). Eutrophication can be simply defined as the "process of enrichment with nutrients" with nitrogen and phosphorous possibly the most important nutrients to consider (Ref. 35). Eutrophication is generally accompanied by increases in plant production, i.e., by increases in the rate of organic synthesis due to the nutrient enrichment, and often by increases in the total plant and animal biomass of a system. This is a natural and long-term, successional process in aquatic systems (as in the aging of lakes) that can be greatly accelerated by certain types of pollution. Eutrophication can be viewed as desirable in a few cases because of the corresponding increase in biomass (e.g., a greater harvest of fish), but it is most commonly viewed as an undesirable process in causing nuisance algae blooms and macrophyte development with the associated odor, taste, toxicity, clogging, and oxygen deficit problems, among others. As a result, for a complete diagnosis of the health of a lake or stream, some assessment should be made of the eutrophic status of the water.

The use of diatom indicator species provides a means for qualitative judgement; however, other, more quantitative approaches should also be employed. Many investigators have utilized artificial substrates such as glass microscope slides as a means of studying the biological conditions of a stream; Patrick (1973) points-out "that the relative amount of biomass on the slides is an excellent way to compare nutrient levels of various bodies of water (Ref. 30)." Such a methodology was utilized in this study since the diatom biomass that develops on a slide can be easily measured via chlorophyll absorbance. This then provides an estimate of the rate of organic synthesis at various stream sites and a means for judging the current eutrophic status of the river, for illustrating productivity changes in the river through the study area, and for estimating the degree of improvement in the river through recent years.

Chlorophyll Accrual Rates--Primary Sites

The development of aquatic algae on glass slides approaches linearity with time through an initial growth phase, i.e., constant rates controlled by nutrient availability in the water; but rates then decline to an asymptote as the carrying capacity of the slides is achieved, defined in part by the slide surface area. As a result, slides have to be removed from experimental sites for analysis during the linear phase in order to obtain comparable data. In the Madison River of Yellowstone National Park, exposures of two to six weeks, depending upon location and season, were necessary for the obtainment of adequate biomass for accurate chlorophyll analyses (Ref. 36 and 37). A 1975 assessment of the Yellowstone River suggested that the Yellowstone is less productive than the Madison (Ref. 38); thus greater exposure times were expected for the former stream. However, data from the Yellowstone indicated that the slides would have to be removed from the water in less than eleven days after submersion in order to avoid the nonlinear phase of the growth curve. This time limit was followed throughout the study and indicates that the periphyton community of the Yellowstone River is possibly more productive than that in Madison given this requisite for a shorter exposure time.

As noted, two time periods were defined for the productivity portion of the study to afford a data check. Chlorophyll accrual rates for these two periods are summarized in Figure 5 for the primary sites on the Yellowstone River. Chlorophyll a was found to be the predominant pigment in periphyton scraped from rocks at the sites. Chlorophyll c was a major secondary pigment, and the absence or negligible concentrations of chlorophyll b indicate that the Bacillariophyceae was the major component of the stream community. This supports the taxonomic observations, and this dominance suggests that the river is in a relatively healthy condition at the present time (Ref. 30).

As indicated in Figure 5, a distinct increase in primary productivity--chlorophyll accrual rates occurs downstream in the Yellowstone River from Laurel to Huntley in both of the seasonal periods. This increase is generally substantiated by the mean 430 millimicron absorbances of the slide-periphyton samples (Figure 6); these measurements were also made since this wavelength represents the peak of the photosynthetic action spectra for many algae (Ref. 40).

Many of the mean differences in chlorophyll accrual rates are statistically significant due to the lack of extensive overlap between maximum-minimum values (Figure 5). This would include the following comparisons: L<D, L<S, L<E, L<H, D<H, and E<H. This was confirmed statistically for the early fall period by using a two-way analysis of variance (randomized complete block design) with subsampling. In this test, sampling site locations were viewed as the treatments with blocking made on date and subsamples by slide location.* The treatment F-ratio was highly significant (F^{3}_{12} = 22.50, significant at <0.005) indicating the occurrence of significant mean differences in chlorophyll accrual rates between treatments (between periphyton samples from different locations on the river). However, the block and subsample F-ratios were insignificant at 10% (F^{4}_{12} = 1.21 and F^{20}_{12} = 0.19 respectively). Appar-

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*The diatometers were constructed with four slots for the inclusion of four, "side-by-side" slides to be aligned parallel to the stream current. As a result, since two of the slides are located on the "outside" and two on the "inside," the "outside" slides would be more directly affected by current and other factors than the "inside" slides. This aspect was noted in the analysis and treatment of the data.

Figure 5. Mean chlorophyll a per day-cm^2 accrual at primary sites in the Yellowstone River through two time periods (L--near Laurel, D--at Duck Creek Bridge, S--at South Bridge, E--at East Bridge, and H--near Huntley).

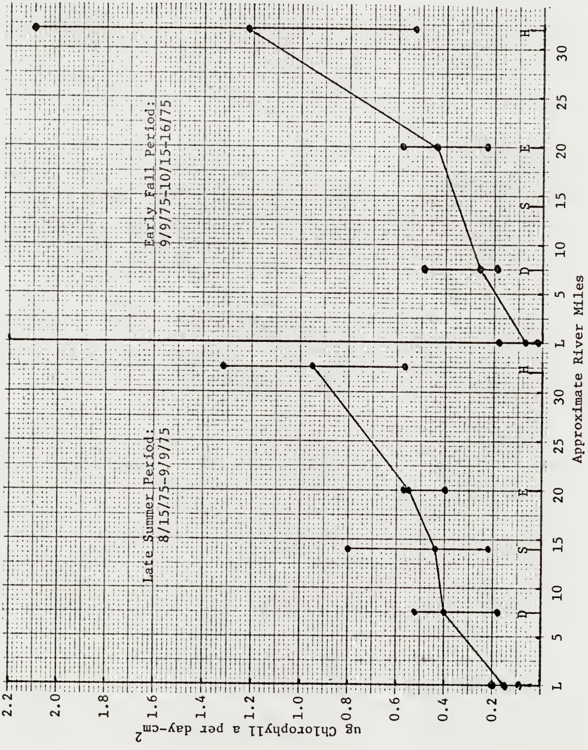
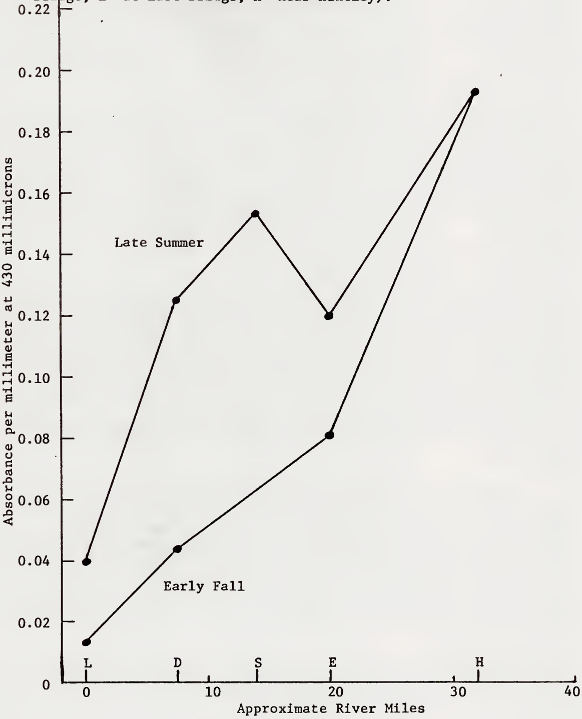


Figure 6. Mean periphyton absorbance at the peak of the photosynthetic action spectrum (wavelength of 430 millimicrons) for two seasons; samples collected via glass slides from the primary sites on the Yellowstone River (L--near Laurel, D--at Duck Creek Bridge, S--at South Bridge, E--at East Bridge, H--near Huntley).



ently slide location in the diatometer did not have a significant affect on chlorophyll accrual in this study; rates for the "inside" slides averaged 0.50 ug chl a per day-cm^2 while rates for the "outside" slides averaged 0.49 ug chl a per day-cm^2.

The patterns of downstream increase in chlorophyll accrual were also quite similar between the two time periods (Figure 5); in both cases, the increase in rates from the upper to the lower station was lowest in the D to E reach and greatest in either the L to D or E to H reach depending upon season. This is illustrated in Table 7. Overall, the increase in productivity was most pronounced in the E to H reach. A 6.3-fold and a 17.4-fold increase in primary productivity--chlorophyll accrual was obtained through the entire Yellowstone River study area (late summer and early fall respectively), approaching a 10-fold mean increase. This appears to be quite distinctive for only a 30 to 35 mile reach of river.

In addition to longitudinal charges in primary productivity, a marked seasonal decline also became evident in the Yellowstone River. This is suggested in Figure 6 and further illustrated in Figure 7 which presents a moving average of chlorophyll accrual rates for all sites through successive two to three week periods. The decline in productivity through late September and early October was quite distinct and paralleled the decline in temperature through this period from summer levels--15.0C to 21.0C in the summer (an average of 17.3C) to 9.4C to 14.7C in the fall (an average of 12.2C).

Chlorophyll Accrual Rates--Secondary Sites

The progressive downstream increase in productivity in the Yellowstone River below Laurel was probably due to successive inputs of water with high concentrations of materials that further stimulate algae growth. Chemical aspects will be considered later. Such inputs can be natural tributaries such as the Clarks Fork River or wastewater discharges such as Yegen Drain which in turn receives effluents from a sugar beet processing plant and an oil refinery, from storm drains, and occasionally from a meat packing plant. Secondary sampling sites were established on the Clarks Fork and Yegen Drain in order to ascertain their effect upon the Yellowstone River. These particular inputs were selected due to the large discharge volumes (loading potential) of the first tributary and the definite pollutive capacity of Yegen Drain.

A diatometer was placed directly in the Clarks Fork River near its mouth at Laurel (site CF); in the second case, the diatometer was placed in the Yellowstone River a short distance below the confluence of the drain. If Yegen Drain were active in stimulating Yellowstone productivity, as suggested by the increase in accrual rates from site E to site H, then a higher accrual rate would be expected in the river directly below the drain than at the "cross-stream, control" station (site E). In turn, relatively high productivities would be also expected in the Clarks Fork River given the marked increase in chlorophyll accrual rates from Laurel to site D on the Yellowstone River (Figures 5 and 6).

A significant stimulation by water from Yegen Drain is evident in the Yellowstone through the higher chlorophyll accrual rates that were obtained

Figure 7. Change in mean chlorophyll accrual rates in the Yellowstone River through the period of study (moving average).

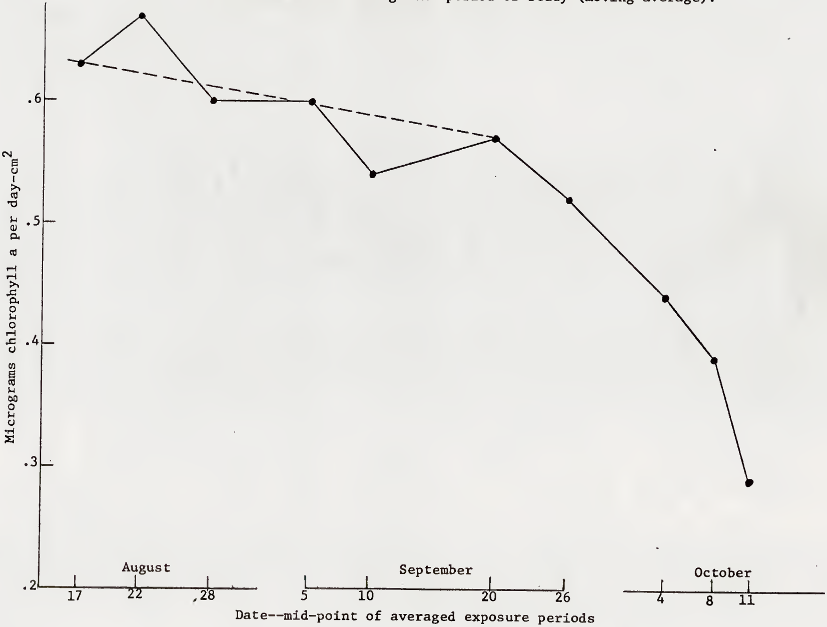


Table 7. Late summer and early fall increases in chlorophyll accrual rates per reach mile of the Yellowstone River between Laurel and Huntley (change in ug chlorophyll as per day-cm^2 per mile); requestial downstream sampling sites: L--Laurel, D--Duck Creek Bridge, S--South Bridge, E--East Bridge, and H--Huntley.

Reach	Reach Miles	Accrual increase per mile (Late Summer)	Accrual Increase per mile (Early Fall)	Average
L-D	7.5	0.034	0.025	0.0295
D-S	6.6	0.006	---	---
S-E	6.2	0.018	---	---
D-E	12.8	0.012	0.014	0.013
E-H	11.7	0.034	0.067	0.0505
L-H	32.0	0.025	0.036	0.0305

in the river below the drain relative to rates in the "cross-stream" site unaffected by this input (Table 8). Though diluted by the subsequent mixing action of the river, such a stimulation would be carried downstream and, in combination with other inputs below site E (e.g., Billings sewage treatment plant), would cause an increase in river productivity as illustrated by the data from site H.

The productivity increase in the Yellowstone River from site L to site D would indicate a similar loading of biostimulants from the Clarks Fork; such a loading from a smaller stream would imply a greater concentration of biostimulants in the tributary and thereby a greater productivity than the mainstem. However, chlorophyll accrual rates in the Clarks Fork River were found to be less than those of the Yellowstone at Duck Creek Bridge and between those obtained at sites L and D (Table 9). The total transmission data (percent light penetration to the slides) in Table 9 suggest that light is a limiting factor in the Clarks Fork reducing its productivity. This in turn relates to the relatively high turbidities and sediment concentrations of the stream (Ref. 9)--an average of 12 JTU for the Clarks Fork from several samples collected during the study period versus corresponding means of 3 JTU and 4 JTU at sites L and D respectively. This effect was apparently carried into the Yellowstone River at Duck Creek Bridge where total transmissions were lower than those at Laurel.

The effect of light on the productivity of streams in the study area is substantiated to some extent by the relationship between total transmission

Table 8. Chlorophyll accrual rates in the Yellowstone River below Yegen Drain and in associated sampling sites on the river for the period of September 15 to October 15, 1976.

	Chlorophyll a accrual as ug per day-cm^2		
	below Yegen Drain	at East Bridge	near Huntley
Minimum	0.420	0.353	0.528
Maximum	1.120	0.584	1.437
Mean	0.726	0.476	1.082

Two-way analysis of variance: treatments (sampling site location)--F_{14}^{2} = 12.28, significant at <0.5%; blocks (dates)--F_{14}^{7} = 1.56, insignificant at 10%.

Table 9. Chlorophyll a accrual rates (CAR as ug per day-cm^2) and percent total light transmission (T) in the Clarks Fork River (CF) and associated Yellowstone River sites (L--near Laurel and D--at Duck Creek Bridge) for the period of September 9 to October 7, 1976.

	L		CF		D	
Date	CAR	T*	CAR	T*	CAR	T*
9/15	0.065	85.3	0.172	27.0	0.443	70.5
9/22	0.051	85.5	0.151	8.8	0.219	58.3
9/30	0.031	86.0	0.202	31.8	0.357	59.0
10/7	0.156	83.8	0.177	65.8	0.184	73.3
Mean	0.076	85.2	0.176	33.4	0.301	65.3

*Total T is an average of transmissions at slide depth (0.39 to 1.48 feet) at the start and the end of an exposure period.

and chlorophyll accrual at sites D and CF (Table 9). In general, chlorophyll accrual rates were lower in those exposure periods having lower total transmissions. The major exception resides in the 10/7/76 data; however, the low rates through this particular period are possibly related to the seasonal-temperature effects described previously (Figure 7). This relationship between light and productivity-photosynthetic activity in algae approaches linearity when light is a limiting factor (Ref. 41). Given this assumption and using mean values from the Laurel location as a control, theoretical productivities not affected by turbidity were calculated for sites D and CF as 0.39 and 0.45 ug chl a per day-cm^2 respectively. These theoretical productivities relative to the value at Laurel (0.08 ug chl a per day-cm^2) conform to expectations and suggest that the Clarks Fork River does have an effect in increasing the productivity of the Yellowstone River. Chemical data also indicate that the Clarks Fork should have had a stimulating effect on the growth of mainstem algae communities. Apparently the high suspended sediment concentrations of this tributary retards its productivity.

Discussion

Differences in the amount of increase in primary productivity (Table 7) through the various reaches of the river in the study area are probably related to the amount and type of tributary-wastewater inputs entering the river through each section. In reaches with the greater increase in chlorophyll accrual downstream, such inputs probably pose a greater loading of materials (amount per time) that stimulate algal growth (e.g. the critical nutrients such as PO_4 and NO_3). As an example, in the D to E reach, only two minor tributaries (Duck Creek and Blue Creek) and one relatively large tributary (Canyon Creek) (with typical summer flows of 3 cfs and 130 cfs respectively) enter the river in addition to the King Avenue Storm Drain and the Corette wastewater discharges (56 cfs); the discharge in Canyon Creek is enhanced by irrigation return flows, and flows in the King Avenue Storm Drain range from near zero to 48-113 cfs (Ref. 9). The increase in productivity was found to be relatively small through this reach in contrast to the L-D section where a major tributary enters the mainstem (the Clarks Fork River with relatively large summer flows typically between 500 and 1000 cfs) in addition to several wastewater inputs--the Laurel Wastewater Treatment Plant discharge (about 2.5 cfs), the Burlington Northern sewer discharge (about 1.5 cfs), the Cenex oil refinery effluent (about 0.5 cfs), and the Underpass Storm Drain (Ref. 9).

Similarly, productivity increases are relatively high through the lower reach of the Yellowstone River in the study area (below East Bridge) which receives water from several natural streams--three minor tributaries (Sevenmile, Twelvemile, and Alkali Creeks with summer flows ranging from intermittency to 1.5 cfs) and two relatively large tributaries (Fivemile Creek and Pryor Creek with summer flows near 20 cfs and 25 cfs respectively)--and from several wastewater sources--Yegen Drain (summer flows about 34 cfs), the Billings Wastewater Treatment Plant (about 15 cfs), and the Exxon oil refinery (about 50 cfs)(Ref. 9 and 42). Average monthly flows in the Yellowstone River at Billings for the period of study range between 4000 and 5300 cfs (Ref. 9).

The stimulatory effects of Yegen Drain and the Clarks Fork River on Yellowstone chlorophyll accrual-productivity have been described previously, but the individual effects of many of the remaining and smaller inputs are difficult to assess due to their small volumes and loads. Chemical information would provide some insight to their effects however; a cumulative influence of biostimulants can be visualized which, similar to the larger inputs, would also contribute to the progressive and marked increase in mainstem productivity. In addition, determinations of whether or not productivity levels in a system are at critical levels is an important aspect of eutrophic assessments. Patrick's (1973) suggestion (Ref. 30) is applicable to this study; accrual data from the Yellowstone River can be compared to that of other streams where the eutrophication-productivity status of a reach has been definitely documented. Accrual data is available for several streams in Montana; in addition, productivity information is available for a variety of streams, lakes, and conditions throughout the United States.

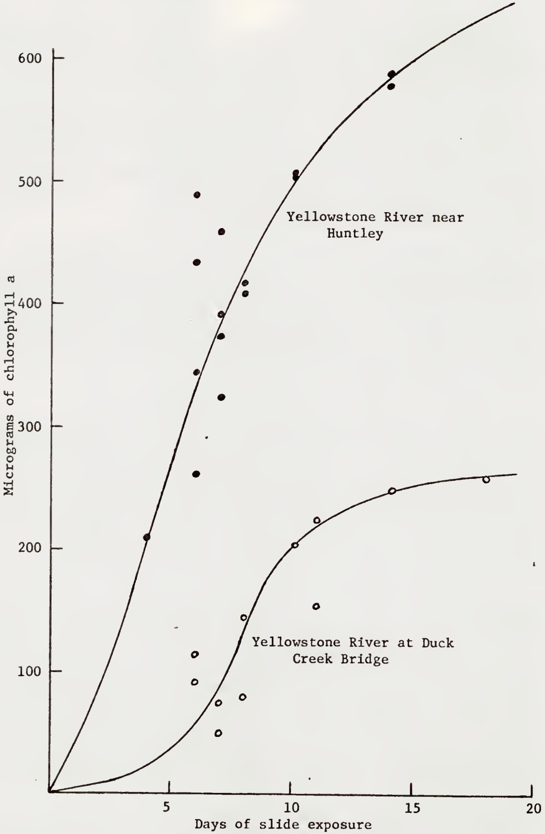
Some chlorophyll data was also obtained from the Yellowstone River in an earlier study but as standing crop rather than accrual rates (Ref. 14). Stadnyk (1971) found an average of 0.16 g chlorophyll per square meter in the river above Billings. Standing crops of periphyton in the Yellowstone River from this study can be estimated by determining the asymptote of the growth curves (Figure 8). This figure indicates that standing crops as chlorophyll a ranged from 270 ug per 39.5 cm^2 (0.07 g per m^2) to 670 ug per 39.5 cm^2 (0.17g per m^2) at sites D and H respectively; these values encompass the average obtained by Stadnyk.

Klarich and Wright (1974) found mean chlorophyll accrual rates in the Madison River ranging from 0.05 ug chlorophyll a per day-cm^2 in the upper river (near Madison Junction, Yellowstone National Park) to 0.005 ug chlorophyll a in the lower river near West Yellowstone, Montana (Ref. 36). The magnitude of productivity change in periphyton is similar to that observed for the Yellowstone River near Billings; however, chlorophyll accrual is much lower in the Madison compared to all locations on the Yellowstone (0.07 to 1.22 ug chlorophyll a per day-cm^2, Figure 5). It should be noted that the photosynthetic activity of a luxurious macrophyte community in the Madison is not included in this particular estimate of productivity.

The periphyton community of the lower Yellowstone River (near Huntley) also appears to be more productive than that in several other Montana streams--the Tongue River in southeastern Montana (less than 0.03 ug chlorophyll a per day-cm^2), the East Poplar River in northeastern Montana (0.009 to 0.019 ug/day-cm^2), the Middle and West Forks Poplar River (0.011 to 0.026 and 0.048 to 0.061 ug/day-cm^2 respectively), and the Poplar River mainstem in northeastern Montana (0.052 to 0.070 ug/day-cm^2 upstream near Scobey and 0.014 to 0.020 ug/day-cm^2 downstream near Poplar) (Ref. 43). In addition, using chlorophyll data available in Bahls (1971), accrual rates were calculated for the East Gallatin River near Bozeman, Montana (Ref. 26). Values were found to range from 0.1 to 0.7 ug chlorophyll a per day-cm^2 under conditions of relatively low current velocity (less than 0.5 m/sec); these values are bracketed by the extremes from the Yellowstone River.

Klarich and Wright (1974), Todd (1967), and Wright and Mills (1967) also estimated the productivity of the Madison River via the upstream-downstream method involving gas exchange (Ref. 36, 37, and 44). The primary productivity of the macrophyte community if included in this type of estimate. Ran-

Figure 8. Chlorophyll accrual with time on glass slides suspended in the Yellowstone River at Duck Creek Bridge and downstream near Huntley, Montana.



ges of net photosynthetic rates for a similar reach of the Madison River were obtained by these investigations as follows (upper to lower section): 1.7 to 0.3gC per day-m^2 (Ref. 44), 1.9 to 0.3gC per day/m^2 (Ref. 37), and 2.1 to <0.01gC per day-m^2 (Ref. 36).

Unlike the Madison River, the Yellowstone lacks a distinct macrophyte community with primary productivity in this stream arising primarily from the periphyton component. McConnell and Sigler (1959) obtained a carbon assimilation ratio of 0.56gC per g chlorophyll a per hour for a mountain stream in Utah (Ref. 45). Using the standing crop information in Figure 8 and McConnell's assimilation ratio, net photosynthetic rates of the periphyton community in the Yellowstone River were determined for comparison to the Madison data of Klarich and Wright (1974), et al. On this basis, net photosynthesis in the Yellowstone was found to range from about 0.4gC per day-m^2 at Duck Creek Bridge to about 1.0gC per day-m^2 near Huntley (assuming an average of eleven hours light per day through the study period). Thus the level of primary productivity in the Yellowstone River (primarily periphyton) appears to be quite similar to that in the Madison if the macrophyte community is included into the latter estimate. This would suggest that the Yellowstone River has the potential for developing aquatic macrophyte growths given certain alterations in the river's annual cycle, e.g., if the scouring action of the spring flood should happen to be eliminated (via Allenspur Dam).

These various comparisons indicate that the Yellowstone River in the vicinity of Billings would probably lie towards the higher end of the productivity spectrum of Montana streams. However, the productivity of the river is not markedly greater nor different from that obtained in the Madison or East Gallatin Rivers for example. Thus the river does not appear to be significantly eutrophic to any extent over that that can occur under natural conditions. That is, the Yellowstone has a level of productivity and productivity change which is similar to that in the Madison River in Yellowstone National Park; this latter stream, due to its location, is not markedly influenced by man-related pollution.

Similar conclusions can be drawn by comparisons to other streams and aquatic ecosystems in the United States. Odum (1959) and Whittaker (1970), drawing upon information from a variety of sources, have listed the typical productivities of a variety of ecosystems and for several specific streams and ponds under pollutive-eutrophic stress (Ref. 39 and 45). Productivities were determined as grams dry organic matter produced per day-m^2 and as a result are not directly comparable to productivity information from the Yellowstone. Chlorophyll a concentration in algae typically comprise one to two percent of the thallus by dry weight. Strickland and Parsons (1972) found that a factor of 60X fairly accurately converts chlorophyll a values to plant dry weight (Ref. 19). Using this factor, chlorophyll rate data from the Yellowstone River study area were converted to grams per day-m^2 for comparative purposes. The maximum value was obtained from the sampling site near Huntley during the early fall (0.73 g/day-m^2) while the minimum was obtained from the site near Laurel, also during the early fall (0.04 g/day-m^2).

This range of values from the Yellowstone River are significantly less than those listed by Odum (1959) for various streams and ponds affected by pollution or enrichment (Ref. 45) (on the order of 0.07% to 14.6%); this in-

cludes for example a polluted stream in Indiana (57g/day-m^2, summer), an enriched, mass algae culture (43g/day-m^2), a pond in South Dakota receiving untreated sewage wastes (27g/day-m^2, summer), a pond in Denmark receiving treated sewage wastes (9.0g/day-m^2, July), a fertilized pond in North Carolina (5.0g/day-m^2, May), and even a turbid river in North Carolina (1.7g/day-m^2, summer). In addition, production in the Yellowstone River is much less than that in a variety of quite productive but natural ecosystems--or examples, Silver Springs, Florida (35g/day-m^2, May), Pacific coral reefs (18.2g/day-m^2), various Texas estuaries (4.4 to 23g/day-m^2), eutrophic lakes (2.1 to 9.0g/day-m^2), and swamps and marshes (2.2 to 11g/day-m^2)(Ref. 39 and 46). Values in the Yellowstone River are most akin to those obtained from less productive ecosystems such as the open ocean (0.5g/day-m^2, Sargasso Sea), deep, oligotrophic lakes (near 0.7g/day-m^2), and bog lakes (e.g., Cedar Bog Lake, Minnesota, 0.3g/day-m^2). Whittaker (1970) has determined that streams have a normal range or production between 0.3 and 4.1g/day-m^2 (Ref. 39); the periphyton community of the Yellowstone River falls within or near the lower end of this range. These comparisons further indicate that the Yellowstone River is not in a eutrophic state at the present time.

RESULTS AND DISCUSSION--WATER CHEMISTRY

General Features

Considerable chemical data and information for the Yellowstone River and tributaries are summarized and discussed in a report entitled Water Quality Inventory and Management Plan--Upper Yellowstone Basin, Montana prepared by the Water Quality Bureau, Montana Department of Health and Environmental Sciences (Ref. 9). The report describes the water in this reach of the river as moderately hard to hard, non-saline, and of a calcium-sodium-bicarbonate composition. The Yellowstone River arises in Yellowstone National Park, and the influences of thermal discharges in this region on the river's chemistry can be seen in the relatively high concentrations of fluoride in its water. Dissolved solid concentrations progressively increase downstream once the river exits the Park, and this parameter varies inversely with flow; in contrast, suspended sediments typically vary directly with flow. As a result, water quality is best during high flow periods (e.g., during the spring flood) although high turbidities often detract from this quality at these times. In general, the quality of water in the Yellowstone River can be rated as good to excellent in the upper Yellowstone Basin (Ref. 9).

Dissolved solid concentrations also increase markedly through the Huntley-Laurel reach of the river. As an example, in an October 1-2, 1974 sampling run, 32% of a 2.2-fold increased in dissolved solids in the stream from Corwin Springs near Yellowstone Park to Huntley was found to occur through the Billings reach (Ref. 9 and 47). Most of the specific, dissolved ionic constituents also demonstrated increases through this reach (Ref. 47). This is a reflection of the poorer quality of water in the various tributaries of the Yellowstone through this section. For example, mean specific conductances (micromhos per cm at 25C) of several samples collected from the major tributaries through the study period were from 1.7 to 10.6 times higher than means from the Yellowstone River. Comparisons were made as follows (mean specific conductance in micromhos) -- Duck Creek (2903), Blue Creek (2094), Five Mile Creek (1003), Alkali Creek (975), the Clarks Fork River (740), and Canyon Creek (684) versus the Yellowstone River near Huntley (401) and near Laurel (272). A mean, 1.5-total increase in dissolved materials was obtained for the mainstem in the study area for this July-October (1975) period. Inputs from the various tributaries listed above no doubt account at least in part for this increase. This would also include pryor Creek which has a specific conductance on the order of 700 to 1000 micromhos during the summer (Ref. 42). If high concentrations of a critical biostimulant were also present in these tributary waters, i.e., a critical nutrient in concentrations limiting to algal growth in the Yellowstone at Laurel, then the progressive inputs of this constituent via the tributaries would result in the increase in productivity that was observed for the Yellowstone River.

Wastewater Influences

In addition to the natural tributaries, various wastewater discharges to the Yellowstone River also play a role in causing the downstream increase of total dissolved solids (TDS) and ionic constituents in the mainstem. Many of these effluents had specific conductances significantly higher than values in the Yellowstone --e.g., the Underpass Storm Drain (3296), the Burlington-Northern effluent (1741), Yegen Drain (677), and the King Avenue Storm Drain (662)(as mean specific conductances in micromhos). The effect of these inputs on the mainstem are probably of a cumulative nature since their individual TDS loads are quite small relative to the Yellowstone River. In addition to TDS, various wastewater effluents also have a pollutive impact in the Yellowstone through the introduction of suspended sediment, organic materials, fecal coliforms, nitrogen and phosphorus nutrients, phenols, thermal loading, and so forth. However, such problems have been greatly rectified in recent years due to abatement efforts.

In terms of suspended sediment, the Clarks Fork River and Pryor Creek also have a pollutive influence on the Yellowstone through the introduction of high silt loads. Suspended sediment concentrations in the two streams during low flow periods (e.g., in the summer) can range between 3.0 and 222 mg/l (Clarks Fork, Ref. 9) and between 26 and 108 mg/l (Pryor Creek, Ref. 42). This is greatly accentuated during high flow periods (e.g., in spring runoff), particularly in Pryor Creek (approaching 3500 mg/l, Ref. 42). An unknown proportion of this sediment problem is due to natural causes; however, a large part of the problem stems from man's mismanagement of the readily erodible land in the streams' drainage basins. These silt inputs thereby represent a major, non-point source of pollution to the Yellowstone.

The discharge of Yegen Drain and the Clarks Fork River are of adequate volumes and with sufficient loads so that a definite effect on the Yellowstone River can be demonstrated through the monitoring of various "field" parameters. Such information was collected periodically throughout the study period and is summarized in Table 10.

The effect of suspended sediment from the Clarks Fork in reducing light transmission at Duck Creek Bridge on the Yellowstone has been considered previously (Table 9). This is again evident in Table 10 through the greater turbidities and suspended sediment levels in the Yellowstone River below the

Table 10. Water Quality of samples collected from the Yellowstone River (YR) and tributaries in 1975--"field" parameters": TA--total alkalinity in me/l, SC--specific conductance in umhos per cm at 25C, turb--turbidity in JTU, TSS--total suspended sediment in mg/l, FC--fecal coliforms as number per 100 ml, DO--dissolved oxygen in mg/l, and BOD--biochemical oxygen demand in mg/l.

	YR-Laurel								Clarks Fork River							
Date	pH	TA	SC	Turb	TSS	FC	DO	BOD	pH	TA	SC	Turb	TSS	FC	DO	BOD
8-22	8.51	2.4	279	2.3	5.8	--	--	---	8.46	4.4	735	18.0	51.0	--	--	----
9-9	8.40	---	269	3.1	6.8	--	--	---	8.42	---	832	13.0	30.2	--	--	----
9-28	8.58	2.5	290	1.8	5.4	--	--	---	8.42	4.8	790	12.0	31.0	--	--	----
10-7	8.38	2.6	294	2.6	5.4	0	--	---	8.41	4.9	890	10.0	21.6	--	--	----
10-16	8.52	2.6	295	3.0	5.2	0	11.1	1.0	8.31	4.4	732	74.0	186.	--	--	----
11-1	----	---	---	---	---	2	----	---	----	---	---	----	----	--	--	----
**Mean	8.48	2.5	285	2.6	5.7	1	11.1	1.0	8.40	4.6	796	25.4	64.0	--	--	----

	YR-Duck Creek Bridge, South Bank*								YR-Duck Creek Bridge, North Bank							
8-22	8.59	2.9	446	6.0	9.2	--	--	---	----	---	---	----	----	--	--	----
9-9	8.67	---	411	3.6	8.6	--	--	---	----	---	---	----	----	--	--	----
9-28	8.59	3.2	481	3.8	5.8	--	--	---	----	---	---	----	----	--	--	----
10-7	8.59	3.2	489	2.9	4.8	--	--	---	8.53	2.9	382	2.5	5.5	--	--	----
10-16	8.42	3.2	494	22.0	52.0	--	--	---	8.45	2.9	381	10.0	33.2	--	--	----
**Mean	8.57	3.1	464	7.7	16.1	--	--	---	----	---	---	----	----	--	--	----
**Mean	8.51	3.2	492	12.5	28.4	--	--	---	8.49	2.9	382	6.3	19.4	--	--	----

* Below the confluence of the Clarks Fork River.

** Means of comparable data.

Table 10. Continued.

	YR-East Bridge								YR--Below Yegen Drain							
Date	pH	TA	SC	Turb	TSS	FC	DO	BOD	pH	TA	SC	Turb	TSS	FC	DO	BOD
8-22	8.45	2.8	399	8.0	20.0	--	--	---	8.39	2.9	432	9.0	25.6	--	--	---
9-9	8.65	---	365	4.5	14.4	--	--	---	----	---	---	---	----	--	--	---
9-28	8.49	2.9	420	5.0	8.5	--	--	---	8.19	3.2	473	7.5	14.4	--	--	---
10-7	8.38	3.1	425	3.6	9.2	320	--	---	8.10	3.2	472	4.6	11.4	23,000	--	---
10-15	8.21	3.1	472	7.0	25.0	250	11.1	1.9	7.99	3.2	505	11.0	30.8	13,500	9.9	2.3
11-1	8.11	4.4	409	5.8	18.4	115	--	---	8.10	3.0	451	8.0	22.2	20,800	---	---
**Mean	8.44	3.0	416	5.6	15.4	228	11.1	1.9	8.17	3.1	471	8.0	20.6	19,100	9.9	2.3

	YR-Huntley							
8-22	8.40	2.9	425	7.5	18.6	--	--	---
9-9	8.60	---	400	3.8	11.8	--	--	---
9-28	8.45	3.0	450	4.3	8.4	--	--	---
10-7	8.32	3.2	458	4.4	9.6	640	--	---
10-15	8.10	3.3	500	9.0	18.2	1860	11.0	1.9
11-1	----	---	---	---	----	620	--	---
**Mean	8.37	3.1	447	5.8	13.3	1040	11.0	1.9

**Means of comparable data.

confluence of the Clarks Fork. Similarily, the influence of the Clarks Fork in increasing TDS concentrations in the Yellowstone River is evident in the specific conductance and total alkalinity data of the table. Both the specific conductance and turbidity-suspended sediment information indicate that the Clarks Fork and mainstem water had not completely mixed at site D since greater values were obtained at the south bank, below the confluence of the tributary, than on the opposite side. An average of comparable mean specific conductances in samples from the two banks at site D (437 umhos) is quite similar to a micromho mean for the same dates using the East Bridge data (449). Both the specific conductance and the total alkalinity values indicate that the increase in TDS in the mainstem was relatively minor following the confluence of the Clarks Fork River. In addition, following the marked increase in suspended sediment-turbidity from sites L to D (apparently due to the Clarks Fork), there was a marked decline and leveling of these variables through reaches D-E and E-H respectively. Apparently the Clarks Fork had by far a greater effect of these types than do the other inputs to the Laurel-Huntley stretch of the Yellowstone River.

The effect of Yegen Drain can be most obviously seen through its introduction of high fecal coliform counts to the Yellowstone River (Table 10). Coliform concentrations in the river below the drain were quite high relative to the levels at sites L and E; though diluted by mixing, this "spike" of fecal coliforms remains in evidence at Huntley. This could also be augmented by inputs from the Billings Wastewater Treatment Plant (0.4 mile below the drain). Some inputs of fecal coliforms also occurred between Laurel and site E as indicated by the increase in counts through this reach (possibly related to the Laurel Wastewater Treatment Plant with fecal counts near 3.0×10^5, Ref. 9). In addition, the relatively minor effects of Yegen Drain on Yellowstone pH, specific conductance, and turbidity - suspended sediment are also evident in the table. Part of the increase in specific conductance and part of the decrease in river pH was possibly attributable to wastewater inputs via this drain.

Critical Nutrients

In considerations of eutrophication, soluable inorganic nitrogen and phosphorous compounds (e.g., PO_4, NO_3, and NH_3) are generally visualized as the critical nutrients in enhancing productivity (Ref. 35). However in recent years, increasing attention has also been given to carbon source availability for photosynthesis (HCO_3 and CO_2) as a eutrophic factor, e.g., Wright and Mills (1967) (Ref. 44). As a result, in the water sampling program of the periphyton-productivity surveys of this study, chemical analyses were directed primarily to these factors along with assessments of light transmittance at the various sites.

Specific criteria describing the critical levels of nitrogen and phosphorous necessary to promote nuisance algal blooms have not been definitely established due to the complexity of relationships between these two constituents and between these two constituents and the remaining components of an ecosystem (Ref. 48). Federal surveys have indicated that 48% of the aquatic sites sampled across the nation had phosphorous concentrations greater than 0.05 mg/l (Ref. 49). In most uncontaminated lakes, phosphorous has been found in the range of 0.01 to 0.03 mg/l although higher values have been obtained in some nonpolluted cases (Ref. 50). In addition, phosphorous levels exceeding 0.2 mg/l have produced no problems in some potable supplies (Ref. 48). Reviewing this information, the Environmental Protection Agency has suggested that total phosphorous in concentrations less than 0.05 mg/l would probably restrict nuisance plant growths in flowing waters (Ref. 48). In contrast, much higher concentrations of inorganic nitrogen are necessary to initiate algal blooms; various studies have indicated that excessive growths of plants are avoided at nitrogen concentrations less than 0.35 mg/l (Ref. 51 and 52). These two values then -- 0.05 mg/l for phosphorous and 0.35 mg/l for nitrogen -- can serve as first order approximations of critical nutrient levels. Waters with both phosphorous and nitrogen exceeding these respective levels can be judged as potentially eutrophic.

In addition to the nitrogen and phosphorous data collected as a part of this study, some similar information is available from previous sampling programs conducted by the Montana Water Quality Bureau on the river (Ref. 9). All of this information is summarized in Table 11 and indicates that distinct increases in $NO_2 + NO_3 - N$ and total soluable inorganic nitrogen (TSIN) occurred downstream in the Yellowstone River from Laurel to Huntley during the study period. A less distinct and less uniform increase also occurred in total - P concentrations downstream although an obvious pattern of orthophosphate-P change was not evident in the river. The critical nitrogen and phosphorous levels were not exceeded by median total-P and TSIN concentrations at any of the primary sites. Of the 59 analyses of individual samples from the river, the critical nitrogen level was exceeded in only 7% of the cases; the critical phosphorous level was exceeded in only 24% of the cases with 71% of these collected from the lower river. Both the nitrogen and phosphorous criteria were exceeded in only two samples (both from site H); this chemical information also suggests that the Yellowstone River is not significantly eutrophic at the present time.

A greater difference is evident between median TSIN values and critical nitrogen levels than between median total-P values and critical phosphorous levels (Table 11); median TSIN concentrations were less than 50% of the critical level at the primary sites whereas total-P concentrations were generally greater than 50% of the critical level (but less than 100%). This would suggest that the Yellowstone River is more nitrogen than phosphorous limited. The relatively high phosphorous concentrations in the river at Laurel (as compared to the critical phosphorous value) are probably derived from Yellowstone National Park; the median orthophosphate-P concentration in thirteen samples from the river above Livingston, Montana was 0.046 mg/l (from data on file with the Montana Water Quality Bureau, Ref. 43). Several other investigations have also demonstrated relatively high orthophosphate levels in the Madison River and other streams originating within the Park (Ref. 9, 36, 44, 53, and 54).

Total-P and TSIN concentrations in the Yellowstone River below Yegen Drain were about 1.5 times greater than the critical P- and N-values and were considerably higher than concentrations in the main river (Table 11). This is in accord with the greater chlorophyll accrual rates that were obtained at this site in relation to site E across the river which was unaffected by this discharge (Table 8). This segment of the river appears to be potentially eutrophic due to the high phosphorous and nitrogen inputs from Yegen

Table 11. Median concentrations of nitrogen and phosphorous species (mg/l) at various locations along the Yellowstone River between Laurel and Huntley, Montana.

Parameter	near Laurel	at Duck Creek Bridge	at South Bridge	at East Bridge	near Huntley	below Yegen
$NO_3 + NO_2 - N$	0.04	0.07	0.12	0.09	0.12	0.21
$NH_3 - N$	<.01	0.01	0.02	0.01	0.05	0.30
Total Soluable Inorganic - N	0.04	0.08	0.14	0.10	0.17	0.51
*Percent	11%	23%	40%	29%	49%	146%
$PO_4 - P$	0.020	0.028	0.023	0.046	0.028	0.046
Total - P	0.022	0.031	0.027	0.047	0.044	0.078
*Percent	44%	62%	54%	94%	88%	156%
P + N	0.062	0.111	0.167	0.147	0.214	0.588

*Nitrogen and phosphorous concentrations as a percent of the critical levels estimated to be necessary for the development of nuisance plant growths and algal blooms (0.35 mg/l N and 0.05 mg/l P).

Drain (Table 12). Similar to Yegen Drain, most tributary streams and wastewater discharges to the Yellowstone River in the study area had greater nitrogen and phosphorous concentrations than the mainstem; in most cases, total-P and TSIN concentrations in these waters were greater than minimum levels deemed characteristic of eutrophic waters (Table 12). Such inputs would provide a nitrogen-phosphorous loading on the river and would therefore account for the increase in these variables from Laurel to Huntley. In addition, nitrogen concentrations in the tributaries were generally at greater levels over the critical value than total-P; the opposite case was obtained for the mainstem where total-P was closer to the critical level (Table 11). As a result, TSIN demonstrated a greater increase in the river from Laurel to Huntley than total-P (a 4.3-fold increase in the former versus a 2.0-fold increase in the latter). This would also indicate that nitrogen was the more critical nutrient in affecting changes in Yellowstone productivity. A 3.5-fold increase in P + N was obtained through the study area (Table 12).

Relatively high pH values were obtained from most of the river samples (Table 10). This would indicate the occurrence of low free carbon dioxide concentrations during a large part of the daylight period which would tend to negate the operation of this variable as a critical eutrophic factor. Mean carbon dioxide concentrations were less than 1.3 mg/l in samples from the primary sites. Such low carbon dioxide concentrations and high pH levels during the day are often indicative of an active photosynthetic removal of carbon sources from the water.

Alkalinity, dissolved solid concentrations (which includes essential elements such as calcium, magnesium, and sulfate) and light might also be eliminated as major influential factors since the direction of change of these variables in the river did not completely correspond to increases in chlorophyll accrual. For example, much higher productivities were obtained at site H than at site D even though mean alkalinity and dissolved solid levels were greater at site D (Figure 5 and Table 10). As an added example, the slight 1.2- and 1.03- fold increases in free carbon dioxide and alkalinity respectively through the E-H section were not in accord with the 2.2-fold increase in mean chlorophyll accrual rates through this reach. In addition, light transmission in the river would act to reduce primary productivity rather than enhance it since light penetration to the slides decreased downstream in contrast to the increase in chlorophyll accrual rates. This can be illustrated for the early fall period as follows (where T is the mean total transmission in percent, and C is the mean chlorophyll accrual rate in ug chlorophyll a per day-cm^2):

	Laurel	Duck Creek Bridge	East Bridge	Huntley
T	82.9	60.2%	53.5%	51.4%
C	0.069	0.259	0.440	1.224

As a result, nitrogen and phosphorous appear to be the critical variables that affected primary productivity in the Yellowstone River; downstream increases in P + N concentrations were closely paralleled by increases in chlorophyll accrual. If light was limiting in the river due to reduced transmissions downstream, then this factor would act to reduce primary productivity from its full potential as established by the sequential increases of nitrogen and phosphorous species in the stream from Laurel to Huntley.

Table 12. Median concentrations of nitrogen and phosphorous species (mg/l) in various major tributaries and wastewater effluents to the Yellowstone River between Laurel and Huntley, Montana

Parameter	Underpass Storm Drain	Burlington Northern	Clarks Fork R.	Duck Cr.	Canyon Cr.	Blue Cr.
$NO_3 + NO_2 - N$	1.8	4.0	0.41	1.25	0.49	0.37
$NH_3 - N$	0.10	0.55	0.02	0.55	0.06	0.06
Total Soluable Inorganic - N	1.90	4.55	0.43	1.80	0.55	0.43
* Percent	543%	1300%	123%	514%	157%	123%
$PO_4 - P$	0.054	0.162	0.031	0.162	0.020	0.020
Total - P	0.060	0.198	0.043	0.198	0.050	0.031
* Percent	120%	396%	86%	396%	100%	62%

Parameter	King Avenue Storm Drain	Yegen Drain	Alkali Cr.	Fivemile Cr.	Pryor Cr.	Miscellaneous Storm Drain
$NO_3 + NO_2 - N$	0.88	0.46	0.89	0.71	0.11	0.64
$NH_3 - N$	0.06	3.05	0.10	0.06	----	0.66
Total Soluable Inorganic - N	0.94	3.51	0.99	0.77	----	1.30
* Percent	269%	1003%	283%	220%	----	371%
$PO_4 - P$	0.077	0.197	0.094	0.048	0.042	0.83
Total - P	0.092	0.400	0.146	0.061	-----	----
* Percent	184%	800%	292%	122%	-----	----

* Nitrogen and phosphorous concentrations as a percent of the critical levels estimated to be necessary for the development of nuisance plant growths and algal blooms (0.35 mg/l N and 0.05 mg/l P).

Periphytic Relationships

Both the community structure and individual species composition of periphyton in the Yellowstone River suggest that the stream is in a relatively healthy condition at the present time and not impacted by major forms of organic pollution (Tables 4 and 6). The low BOD's and high dissolved oxygen concentrations (typically near saturation) generally obtained from the river in the study area confirm this contention (Ref. 9 and 43 and Table 10). Values of pH in samples from the stream were consistently greater than 7.0 (Ref. 9 and Table 10) with the major proportion of diatom species collected from the river requiring pH's greater than this value for best development (Ref. 24). These alkaphilous species were also primarily of an oligo-mesothermal, eutythermal nature requiring temperatures of less than 30C for optimum growth but tolerant of wide temperature fluctuations below this level (Ref. 24) (features of a temperate, cold-water habitat). Water temperatures obtained from the Yellowstone River were much less than 30C, typically less than 21C, with a marked decrease to the fall portion of the study period (near 9C). In addition, the bulk of the diatom species from the river were freshwater forms requiring specific conductances of less than 750 umhos for optimum growth (Ref. 24); values of this parameter in the Yellowstone River were consistently less than 750 umhos (Table 10) which provides an adequate condition for these oligohalobous species. Such species in the Yellowstone study area are quite tolerant of salinity below this level, however, as illustrated by the similarity of flora in the mainstem and in the Clarks Fork River (Tables 1, 2, and 4) regardless of the much higher dissolved solid concentrations in the latter stream (Table 10).

The periphyton community in the Yellowstone River is characterized by a gradual downstream change in composition which is synonomous with the natural, successional continuum that occurs in most streams. The major disruption of this continuum relates to the confluence of the Clarks Fork River; the effect of this major tributary on Yellowstone periphyton is illustrated in Figure 2 and Table 4 while the corresponding chemical effect on the mainstem is evident through the marked increases in specific conductance - dissolved solids, alkalinity, and turbidity along with the reduction in light transmission below its confluence (Tables 9 and 10). However, the periphyton compositions of the Clarks Fork and the Yellowstone at site D indicate that the quality of water is good in the tributary and that it does not have a discernible, negative effect on the mainstem. The effect of sediment inputs from the Clarks Fork was not evident in the periphyton community of the mainstem. For example, Synedra ulna was present in the Clarks Fork River (and at sites associated with Yegen Drain) and is characteristic of "dirty water" (Ref. 24 and 55); however, this species was absent from all primary sites on the Yellowstone River. (Similar to the Clarks Fork, samples from sites associated with Yegen Drain also had relatively high turbidities and low light transmissions indicative of "dirty water"; this possibly accounts for the occurrence of Synedra ulna at these locations.)

The periphyton community of the Clarks Fork River was composed of a high percentage of Nitzschia species (Table 2) which is indicative of high concentrations of nitrogen compounds (Ref. 28). This is evident to some extent in the chemical data from the stream (Table 12). Since the Clarks Fork River is quite large, it has a marked loading potential on the Yellowstone River. As a result, since TSIN concentrations in the Clarks Fork were somewhat higher than the mainstem, this coupled with the tributary's volume results in a nutrient enrichment of the Yellowstone River; this appears to be the major effect of the Clarks Fork on the mainstem.

Similar to the Clarks Fork, the main effect of Yegen Drain on the Yellowstone also appears to be one of gross nutrient enrichment, but primarily via concentration rather than by volume in this instance (Table 12). The proportions of Nitzschia species and individuals were quite high in the drain (Table 2). In addition, this wastewater appears to be pollutive in the true sense of the word; the periphyton of the drain and associated sites (i.e., the Yellowstone below Yegen) are characterized by a high occurrence of non-diatom algae (indicative of pollution) (Table 3) and by a high proportion of pollution tolerant diatoms--Navicula cryptocephala, Nitzschia palea, Surirella ovata, and Synedra ulna. In turn, the pollutive capacity of the drain is also illustrated by the high fecal counts (Table 10) in the Yellowstone below its confluence and by the high BOD levels and low dissolved oxygen concentrations of samples from the drain (e.g., up to 10.0 mg/l and down to 5.0 mg/l respectively, Ref. 43). However, the Yellowstone River appears to recover very rapidly below the confluence of the drain with the drain's effects largely eliminated by Huntley.

The major change in the Yellowstone River through the study area is a gradual but pronounced increase in critical nutrient concentrations, primarily nitrogen, from Laurel to Huntley (Table 11) which is paralleled by a percentage increase in the number of Nitzschia species and individuals tabulated in the corresponding periphyton samples (Figure 3). Such TSIN and total-P increases in the Yellowstone River result from the inputs of various tributary streams (e.g., the Clarks Fork River and Yegen Drain) which have high critical nutrient concentrations, particularly the nitrogen species (Table 12). This in turn is reflected in the marked downstream increase of primary productivity in the mainstem river (Figure 5).

Relationships to Primary Production

As indicated previously, increases in chlorophyll accrual rates through the Yellowstone River corresponded most closely to changes in nitrogen and phosphorous concentrations (Figure 5 and Table 11). Apparently either or both of these nutrients acted as the major biostimulant in the river. Nitrogen appears to be the most limiting factor since its concentrations were further below the critical level for eutrophication than the case with total-P. Both of these variables and chlorophyll accrual rates increased downstream from Laurel although the increase in nitrogen along with accrual was most consistent from site to site. As a result, causal relationships were more distinct with TSIN than with total-P. This was substantiated through correlation analyses where simple correlation coefficients of $r=0.910$ (significant at 1% with seven degrees of freedom) and $r=0.716$ (significant at 5% with seven degrees of freedom) were obtained between chlorophyll accrual and TSIN and with total-P respectively. In contrast, insignificant correlations were obtained between chlorophyll accrual and dissolved solids (specific conductance) and between accrual and alkalinity (e.g., $r=0.531$ for alkalinity which was insignificant at 10% with six degrees of freedom).

The best correlation was obtained between chlorophyll accrual and P + N concentrations (Table 11) with r=0.923 and significant at 1%. Apparently both phosphorous and nitrogen were limiting to some extent in the river although the latter nutrient appeared to be the more critical factor. Partial correlations of r=0.841 (significant of 1% with six degrees of freedom) and r=0.412 (insignificant at 10%) were obtained for nitrogen and phosphorous respectively. This also suggests that nitrogen was the more critical nutrient. A significant multiple correlation coefficient of R=0.926 was also obtained (significant at 1%). The coefficient of determination indicates that about 86% of the variation in chlorophyll accrual through the primary sites of the Yellowstone River was related to variations in the independent variables (nitrogen and phosphorous species). As a result, the downstream increase in total soluable inorganic nitrogen derived from various tributary streams (and wastewater discharges) probably produced the pronounced increase in primary production that was observed through the Yellowstone River from Laurel to Huntley. Increases in total-P probably played a minor role. This is in accord with the observation of Gerloff and Skoog (1957) that nitrogen generally appears to be the more critical factor in limiting algal growth in natural waters (Ref. 56).

Neither the chemical nor the productivity data indicates that the Yellowstone River is eutrophic at the present time, even in the lower, more productive reach. Approximately a 2.0-fold increase in nitrogen coupled with a 1.2-fold increase in phosphorous would probably be needed for an approach to eutrophy in the lower section of the river. In the upper river these factors would approach 9.0 and 2.5 respectively. Future abatement and management efforts along this reach of the river would be expected to result in an avoidance of nutrient enrichment approaching these magnitudes.

SUMMARY AND CONCLUSIONS

The Yellowstone River in the vicinity of Billings is decidedly a "young" stream in being located relatively close to its headwaters, i.e., the water has not had a chance to "age". This is illustrated by the relatively low 430/665 absorbance ratios obtained from the periphyton samples from the stream (generally less than 3.0); high ratios, greater than 3.0, are indicative of old and stable ecosystems (Ref. 57). As a result, a true phytoplankton community has not had the opportunity to develop which leaves the benthic algae as the major source of primary production. This algae thereby is a major aquatic resource since it is a source of food for aquatic invertebrates (herbivores) which in turn are eaten by fish and other carnivores. In turn, this periphyton functions to reoxygenate water and to recycle certain pollutants (e.g., ammonia), rendering them less noxious. They also serve as indicators of pollution. Thus an assessment of periphyton is an essential aspect in the evaluation of stream health.

Based on the composition and structure of algae and diatom associations, the Yellowstone River between Laurel and Huntley can be described as having a moderately hard, nonsaline, well oxygenated, and cool, flowing water. The downstream change in periphyton composition is typical of the successional continuum found in most stream ecosystems. The health of the river appears to be quite good at the present time with pollutive influences best described as mild. This conclusion is based on the occurrence and high relative abundances of pollution sensitive diatom species throughout the river in the study area. In addition, species diversity in the periphyton samples from the river was quite high at all locations. Diversity in ecological systems is generally associated with stability and health in a positive manner; a greater diversity implies more functional interrelationships in a community that is less severely stressed environmentally (Ref. 15); i.e., the Yellowstone, having high diversities, is in good shape.

Three influences were noted on the periphyton continuum of the river in this survey--the Clarks Fork River, the Corette discharge, and Yegen Drain; the latter two influences involve respectively temperature effects and an organic-nutrient enrichment whereas the former involves a dissolved solid-suspended sediment loading. However, the effects of these inputs on the periphyton are not pronounced and the river quickly recovers below their confluences. As suggested by Bahls and Bahls (1975), "self-purification and recovery of the community from pollution may be considered as complete at Huntley (Ref. 15)." Comparisons of periphyton samples from the river near Laurel and near Huntley indicate that the Yellowstone wat not indelibly affected by various perturbations through Billings and the study area as a whole.

The major effect of such tributary and wastewater inputs to the stream was the resultant gradual but distinct increase in nitrogen and phosphorous concentrations along the river from Laurel to Huntley. This is paralleled by an increase in the proportion of Nitzschia species and individuals in the periphyton samples and by a distinct increase in chlorophyll accrual - primary productivity downstream through the river reach. Nitrogen was found to be the major limiting factor in the river; tributaries and wastewater discharges had relatively high levels of total soluable inorganic nitrogen, and sequential inputs from these sources increased concentrations in the Yellowstone causing the 6 to 17-fold increases in production. However, neither the productivity rates nor the concentrations of nitrogen and phosphorous were at levels characteristic of eutrophication. As a result, the Yellowstone River is apparently neither eutrophic nor oligotrophic but best characterized as being mesotrophic at the present time.

Apparently the condition of the Yellowstone River in the vicinity of Billings has been greatly improved from past years due to the efforts of recent abatement programs. This survey generally supports the conclusion of a 1972 water pollution control report by the Montana Water Quality Bureau (Ref. 7). Discussions of the Yellowstone River in various earlier reports described the severe condition of the river at the time. Three excerpts from these reports can be quoted as examples:

> The ditch discharge was very turbid in November (Yegen Drain), frequently contained oil and blood, and floating solids tended to accumulate near its mouth. Blood and bits of animal tissue are often present in water passing the bridge on U. S. Highway 87. Dead fish are common in this region. Below this bridge the sewage plant outfall introduced grayish primary effluent, and the lower oil refinery discharges a greenish liquid. Upstream from

> the lower oil refinery outfall whitish sulfur deposits covered coarse algal filaments on the bottom. Fragments of these growths collected on screens at the oil refinery water intake and necessitated frequent cleaning (Ref. 1).
>
> The majority of tastes and odors occurring in surface water supplies originates either in wastes discharged to watercourses or in algal or fungus growths. Algal increases to nuisance levels are induced by nutrients contained in waste discharges . . . . (Ref. 1).
>
> Analysis of collections of attached algae taken during late August, 1961 were completed and the predominant alga was identified as _Cladophora fracta_. The most common alga during 1955 was reported as _Caladophora_ spp. also. A very luxuriant growth of this alga was apparent during the summer of 1961 . . . . A "musty" odor in the municipal water supply reported by the Laurel water department during early September, 1961 was undoubtedly caused by the profuse growth of _Cladophora_ which developed during the summer (Ref. 6).

Such descriptions would definitely imply marked pollutive and eutrophic conditions. The survey completed in 1975 indicates that this is not the case today.

REFERENCES

1. Montana State Board of Health, Helena; State Department of Health, Bismarck, North Dakota, and the United States Public Health Service (HEW, Region VI). 1956. Yellowstone River Pollution Study, November, 1955--Pollution of the Yellowstone River as Related to Taste and Odor Problems in Municipal Water Supplies in Montana and North Dakota. Helena. 31 pp.

2. Boland, R. (undated) Field investigation--Yellowstone River in vicinity of Billings. Report on file with the Water Quality Bureau, Montana Department of Health and Environmental Sciences, Billings. 3 pp.

3. Spindler, J. 1966. Field investigation--Yellowstone River between Billings and Huntley. Report on file with the Water Quality Bureau, Montana Department of Health and Environmental Sciences, Billings, January. 5 pp.

4. Montana State Board of Health. 1963. Water pollution in the Yellowstone River drainage in Montana. Helena. 47 pp.

5. Borchardt, F. and J. Spindler. 1963. Field investigation--Yellowstone River aquatic life, Billings to Huntley area. Report on file with the Water Quality Bureau, Montana Department of Health and Environmental Sciences, Billings. November. 4 pp.

6. Montana State Board of Health. 1965. Progress report on the reduction of wastes reaching the Yellowstone River drainage in Montana. Helena. 78 pp.

7. Billings Branch Office, Water Quality Bureau. 1972. Yellowstone County--Water Pollution Control Report. Montana Department of Health and Environmental Sciences, Helena. May. 22 pp.

8. Bishop, C. 1974. Personal interview with district fisheries manager, Montana Department of Fish and Game, Billings. June 25.

9. Karp, R., D. Klarich, and M. Botz. 1975. Water Quality Inventory and Management Plan--Upper Yellowstone Basin, Montana (Preliminary Draft). Water Quality Bureau, Montana Department of Health and Environmental Sciences, Helena. September. 153 pp.

10. Butcher, R. W. 1947. Studies in the ecology of rivers. VII. The algae of organically enriched waters. Jour. Ecol., 35:186-191.

11. Blum, J. L. 1957. An ecological study of the algae of the Saline River, Michigan. Hydrobiol., 9(4):361-408.

12. Patrick, R. 1963. The structure of diatom communities under varying ecological conditions. Ann. N.Y. Acad. Sci., 108(2):359-365.

13. Bahls, L. L. 1975. Microflora of the Yellowstone River: A progress report. Proceedings of the Fork Union Coal Symposium, Volume 2, Montana Academy of Sciences, Eastern Montana College, Billings. April. Pages 195-198.

14. Stadnyk. L. 1971. Factors Affecting the Distribution of Stoneflies in the Yellowstone River, Montana. Ph.D. Thesis, Montana State University, Bozeman.

15. Bahls, L. L. and P. A. Bahls. 1975. Pollution detection with diatoms: the Yellowstone River between Laurel and Huntley. Report prepared for the Water Quality Bureau, Montana Department of Health and Environmental Sciences, Billings; Hannaea, Helena. 26 pp.

16. Margalef, R. 1951. Diversidad do especies en las communidades naturales. P. Inst. Biol., Apl., 9:5-27.

17. Whittaker, R. H. and C. W. Fairbanks. 1958. A study of plankton copepod communities in the Columbia Basin, southeastern Washington. Ecology, 39:46-65.

18. Patrick, R., M. H. Horn, and J. H. Wallace. 1954. A method for determining the pattern of diatom flora. Not. Nat., Phil. Acad. Nat. Sci., 259: 1-12.

19. Strickland, J.D.H. and T. R. Parsons. 1972. A Practical Handbook of Seawater Analysis. Bulletin 167 (2nd Edition), Fisheries Research Board of Canada, Ottawa, Canada.

20. United States Geological Survey. 1966-1974. Water Resources Data for Montana. Part 2. Water Quality Records. United States Department of the Interior, Helena, Montana.

21. United States Environmental Protection Agency. 1974. Methods for Chemical Analysis of Water and Wastes. Washington, D.C.

22. APHA, AWWA, and WPCF. 1971. Standard Methods for the Examination of Water and Wastewaters. 13th Edition. American Public Health Assn., New York, New York. 874 pp.

23. Rainwater, F. H. and L. L. Thatcher. 1960. Methods for Collection and Analysis of Water Samples. U. S. Geol. Surv. Water Supply Paper, 1454; Geological Survey, United States Department of the Interior, Washington, D.C.

24. Lowe, R. L. 1974. Environmental Requirements and Pollution Tolerance of Freshwater Diatoms. Environmental Protection Agency, Environmental Monitoring Series, EPA-670/4-74-005; United States EPA National Research Center, Cincinnati, Ohio. 333 pp.

25. Cholnoky, B. J. 1968. Die Okologie der Diatomeen in Binnengewassern. J. Cramer, Lehre. 699 pp.

26. Bahls, L. L. 1971. Ecology of the Diatom Community of the Upper East Gallatin River, Montana with in situ Experiments on the Effect of Current Velocity on Features of the Aufwuchs. Ph.D. Thesis, Montana State University, Bozeman. 145 pp.

27. Bahls, L. L. 1973. Diatom community response to primary wastewater effluent. Journ. Water Poll. Control Fed., 45(1):134-144.

28. Cholnoky, B. J. 1960. In Harrison, A. D., P. Keller and D. Dimovic. Ecological studies on Olifantevlei, near Johannesburg: with notes on the diatoms by B. J. Cholnoky. Hydrobiol., 15:89-134.

29. Aagaard, F. C. 1969. Temperature of Surface Waters in Montana. United States Geological Survey and Montana Department of Fish and Game, Helena.

30. Patrick, R. 1973. Use of algae, especially diatoms, in the assessment of water quality. In: Biological Methods for the Assessment of Water Quality, J. Cairns, Jr. and K. Dickson, editors. ASTM Special Technical Publication 528, American Society for Testing and Materials, Philadelphia. Pages 76-95.

31. Wilhm, J. L. 1970. Range of diversity index in benthic macroinvertebrate populations. Jour. Water Poll. Control Fed., 42(5):221-224.

32. Weber, C. I., editor. 1973. Biological Field and Laboraboty Methods for Measuring the Quality of Surface Waters and Effluents. Environmental Protection Agency, Environmental Monitoring Series, EPA-670/4-73-001; United States EPA National Research Center, Cincinnati, Ohio.

33. Newell, R. L. 1975. Yellowstone River study: annual progress report. Montana Department of Fish and Game and Tenneco, Inc., Glendive. 20 pp.

34. Bahls, L. L. 1976. Personal communication with ecologist, Hannaea, concerning periphyton collections from the Yellowstone River by the Montana Department of Fish and Game (in September, 1974). Helena. January.

35. Stewart, K. M. and G. A. Rohlich. 1967. Eutrophication--A Review. Publication No. 34, California State Water Quality Control Board, Sacramento. 188 pp.

36. Klarich, D. A. and J. C. Wright. 1974. Effect of removal of wastewater treatment plant effluent from the Madison River, Yellowstone National Park. A final report for contract CX 6000-3-075, National Park Service. Department of Biology, Montana State University, Bozeman. 44 pp.

37. Todd, E. H. 1967. Primary Productivity of the Madison River in Yellowstone National Park, Wyoming. Ph.D. Thesis, Montana State University, Bozeman. 120 pp.

38. Stevens, Thompson and Runyan, Inc. 1975. Yellowstone Regional Assessment Study. Volume II (Preliminary Draft). 587 pp.

39. Whittaker, R. H. 1970. Communities and Ecosystems. The Macmillan Company, Collier-Macmillan Limited, London. 162 pp.

40. Machlis, L. and J. G. Torrey. 1956. Plants in Action. W. H. Freeman and Company, San Francisco. 282 pp.

41. Round, F. E. 1965. The Biology of the Algae. Edward Arnold Ltd., London. 269 pp.

42. Karp, R. and M. Botz. 1975. Water Quality Inventory and Management Plan--Middle Yellowstone River Basin. Water Quality Bureau, Montana Department of Health and Environmental Sciences, Helena. March. 177 pp.

43. Billings Branch Office, Water Quality Bureau. 1975. Unpublished data on file with the Bureau collected in the fall of 1975. Montana Department of Health and Environmental Sciences, Billings.

44. Wright, J. C. and I. K. Mills. 1967. Productivity studies on the Madison River, Yellowstone National Park. Limnol. Oceanog., 12:568-577.

45. McConnell, W. J. and W. F. Sigler. 1959. Chlorophyll and productivity in a mountain river. Limnol. Oceanog., 4:335-351.

46. Odum, E. P. 1959. Fundamentals of Ecology. Second Edition. W. B. Saunders Company, Philadelphia. 546 pp.

47. Karp, R., D. Klarich, and M. Botz. 1975. Water Quality Inventory and Management Plan--Lower Yellowstone River Basin, Montana (Preliminary Draft). Water Quality Bureau, Montana Department of Health and Environmental Sciences, Helena. March. 136 pp.

48. Report of the Committee on Water Quality Criteria. 1973. Water Quality Criteria, 1972. Environmental Studies Board, National Academy of Sciences and National Academy of Engineering. EPA-R3-73-033, Environmental Protection Agency, Washington D.C. March. 594 pp.

49. Gunnerson, C. 1966. An Atlas of Water Pollution Surveillance in the U.S., October 1, 1957 to September 30, 1965. Federal Water Pollution Control Administration, United States Department of the Interior, Cincinnati, Ohio. 78 pp.

50. Salvato, J., Jr. 1958. Environmental Sanitation. John Wiley and Sons, Inc., New York. 637 pp.

51. Muller, W. 1953. Nitrogen Content and Pollution of Streams. Water Pollution Abstracts, 28 (2): Abstract No. 454.

52. Mackenthun, K. 1969. The Practice of Water Pollution Biology. Federal Water Pollution Control Administration, United States Department of the Interior, Washington, D.C. 281 pp.

53. Roeder, T. 1966. Ecology of Diatom Communities of the Upper Madison River System, Yellowstone National Park. Ph.D. Thesis, Montana State University, Bozeman. 85 pp.

54. Rasmussen, S. 1968. Composition and Structure of Macrophyte Vegetation of the Firehole River, Yellowstone National Park, as Related to Physical and Chemical Factors. Masters Thesis, Montana State University, Bozeman. 46 pp.

55. Gemeinhardt, K. 1926. The systematics, cytology and ecology of the genus Synedra. Pflanzenforschung (Jena), 6:1-88.

56. Gerloff, G. and F. Skoog. 1957. Nitrogen as a limiting factor for the growth of Microcystis aeruginosa in southern Wisconsin lakes. Ecology, 38 (4): 556-561.

57. Odum, E. P. 1963. Ecology. Holt, Rinehart, and Winston, New York. 152 pp.

58. Karp, R., W. H. Garvin. M. K. Botz, and D. Klarich. 1976. Waste Load Allocation Investigation of the Yellowstone River in the Vicinity of Billings, Montana (In Preparation). Water Quality Bureau, Montana Department of Health and Environmental Sciences, Helena. November.